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A Revision of the Australian Endemic Clam Shrimp Genus *Limnadopsis* Spencer & Hall (Crustacea: Branchiopoda: Spinicaudata: Limnadiidae)

BRIAN V. TIMMS

Research Associate, Australian Museum, 6 College Street, Sydney NSW 2010, Australia
brian.timms@gmail.com

ABSTRACT. Species of *Limnadopsis* Spencer & Hall occur in temporary pools in arid and semi-arid areas of Australia. The genus is redefined and *Limnadopsium* Novojilov treated as a junior synonym. As in other spinicaudatans, most morphological characters are variable, this variability is given in expanded and rewritten descriptions of the three previously described species: *L. birchii* Baird, *L. parvispinus* Henry, and *L. tatei* Spencer & Hall. Five additional species from northern and western parts of Australia are described: *L. minuta* n.sp., *L. multilineata* n.sp., *L. occidentalis* n.sp., *L. paradoxa* n.sp., and *L. pilbarensis* n.sp. *Limnadopsis brunneus* Spencer & Hall is considered a nomen dubium. The most useful features for discriminating species are the shape of the carapace, the relative development of the dorsal carinae of the carapace, the number and relative size of the telsonic denticles, the number of spines on the cercopods, and the surface morphology of the eggs. A key is provided for all species. Western Australia has six species; much of the rest of Australia has 2–3 species, but none has been recorded from relatively well watered Victoria, Tasmania, and north Queensland.

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Of the eight genera of clam shrimps (within the Laevicaudata, Spinicaudata, and Cyclestherida) known so far from Australia, only *Limnadopsis* is endemic (Richter & Timms 2005). This genus was erected by Spencer & Hall (1896) to accommodate three new species, *L. squirei*, *L. tatei*, and *L. brunneus*. Central to their genus definition was the presence of "spinous processes on the dorsal edge of the carapace", and the presence of 26–32 pairs of legs. Sayce (1903) realized what was then known as *Estheria birchii* (of Baird 1860) was synonymous with *L. squirei*, and so designated the latter as the type of *Limnadopsis*. Henry (1924) added a new species *L. parvispinus*, but this publication went virtually unheeded (e.g., Novojilov 1958, Thiéry 1996). Much later Novojilov (1958) thought all three of Spencer & Hall's (1896) species were so different from each other that they represent three different genera, so he split off *L. tatei* into a new genus *Limnadiopsium*, but he never proposed a new genus for *L. brunneus*. Daday (1925) confused the spelling and definition of *Limnadopsis*, and this problem continues (Novojilov 1958, Straškraba 1965a, Thiéry 1996, Dumont & Negrea 2004), although Brtek (1997) corrected the spelling of *Limnadopsis, L. birchii*, and *L. squirei*. Some authors (e.g., Richter & Timms 2005) have not recognized *Limnadiopsium*, and there are problems with the descriptions of *L. parvispinus* and *L. brunneus* (Richter & Timms 2005), all of which further confuse the taxonomy of this group. The only other study on the genus is by Pabst & Richter (2004), on larval development in *L. parvispinus*.

Four undescribed species of *Limnadopsis* have been found in Western Australia, and another nearby in the Northern Territory. Given the confused state of the taxonomy of this genus and its associates, it is the aim of this paper to revise the genus.

Material and methods

Collections of *Limnadopsis* were examined in the Australian Museum, Sydney (AM), Queensland Museum, Brisbane (QM), South Australian Museum, Adelaide (SAM), National Museum of Victoria, Melbourne (NMV), Western Australian Museum, Perth (WAM), Museum and Art Gallery of the Northern Territory, Darwin (MAGNT), the corporate collections of staff of the Department of Conservation, Western Australia (DEC), and the personal collections of M.C. Geddes and the author. Information on collections is not uniform, especially for older material in museums. Measurements were made using a stereomicroscope and a template placed under the specimens and marked in half millimetres (accurate to ±0.25 mm). Drawings of whole animals, heads, and telsons were made with the aid of an ocular drawing tube. For further information on collections by the author from the Paroo region (Currawinya National Park; Bloodwood, Muella, Rockwell and Tredega Stations) see Timms & Richter (2002). Some information on collections by DEC is available in Halse *et al.* (2000) and Pinder *et al.* (2004).

Various authors (e.g., McLaughlin, 1980) have used many terms to describe the features of clam shrimps. For general body parts, I follow Richter & Timms (2005), except I use caudal claws (rather than caudal furcae) and for the claspers I follow Olesen *et al.* (1996).

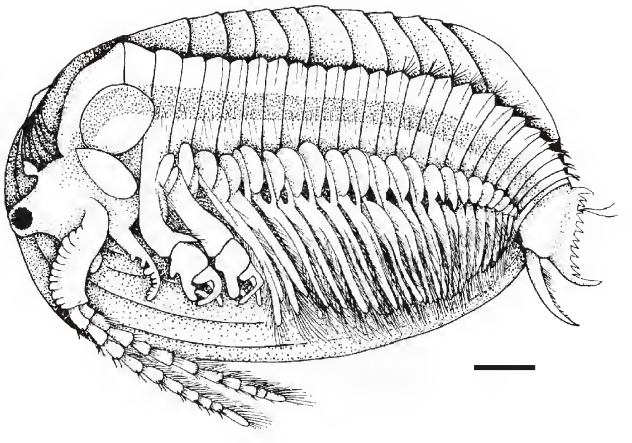

Fig. 1. General view of *Limnadopsis pilbarensis* n.sp. Drawn by Jane McRae.

Systematics

Subphylum Crustacea Brünnich, 1772

Class Branchiopoda Latreille, 1817

Order Diplostraca Gerstaecker, 1866

Suborder Spinicaudata Linder, 1945

Family Limnadiidae Baird, 1849

Genus *Limnadopsis* Spencer & Hall, 1896

Diagnosis. Umbo poorly developed, but present; carapace with many well expressed growth lines; growth lines in some species projecting as carinae along dorsal margin of carapace; head with a frontal organ on the apex of a posteriorly situated pyriform appendage; first antennae bar-shaped bearing many (5–13) lobes; 24–32 pairs of thoracopods; male with anterior-most two pairs of thoracopods modified as claspers, with the movable finger terminating in 1–3 spines, instead of a suctorial organ as in other limnadiids. First spine of the dorsal spine row of the telson large and protruding from the general alignment of the telson's dorsal surface.

Remarks

In the original diagnosis by Spencer & Hall (1896), emphasis was placed on the 10–15 clearly marked growth lines, the "dorsal line, which is raised into a much-compressed spiney keel", and the large number (26–32 pairs) of limbs. Henry (1924) and Daday (1925) continued in this vein, oblivious to the virtual lack of spiny outgrowths (i.e. carinae) and the large number (ca 30) of growth lines in *L. brunneus*. Likewise Novojilov (1958) was most impressed by the spiny dorsal outgrowths, so much so that he erected the subfamily Limnadopsinae based on this character, containing *Limnadopsis* and his *Limnadiopsium*. Straškraba (1965a), and Thiéry (1996) followed Novojilov (1958) in their definitions of the subfamily Limnadopsinae, using the spiny outgrowths as their only diagnostic feature. Given that in *L. brunneus, L. parvispinus*, and five new species described below, these spiny outgrowths are absent or minimally expressed, this character cannot be used alone as a major distinguishing feature of *Limnadopsis* or the subfamily.

Many of the other characters mentioned in the diagnosis are also not unique to *Limnadopsis*, or are not universal in the genus. However, all species of *Limnadopsis* have the first spine of the dorsal spine row of the telson large and protruding from the general alignment of the telson's dorsal surface. All species also have, well-expressed lines of growth on the carapace. However in *L. parvispinus* the lines are less well expressed than in other species, but still quite different from the few poorly expressed lines that are typical for the remainder of the Limnadiidae, except in *Metalimnadia* (Straškraba, 1965a). *Metalimnadia* differs from *Limnadopsis* in lacking a frontal organ, in having a well-developed umbo,

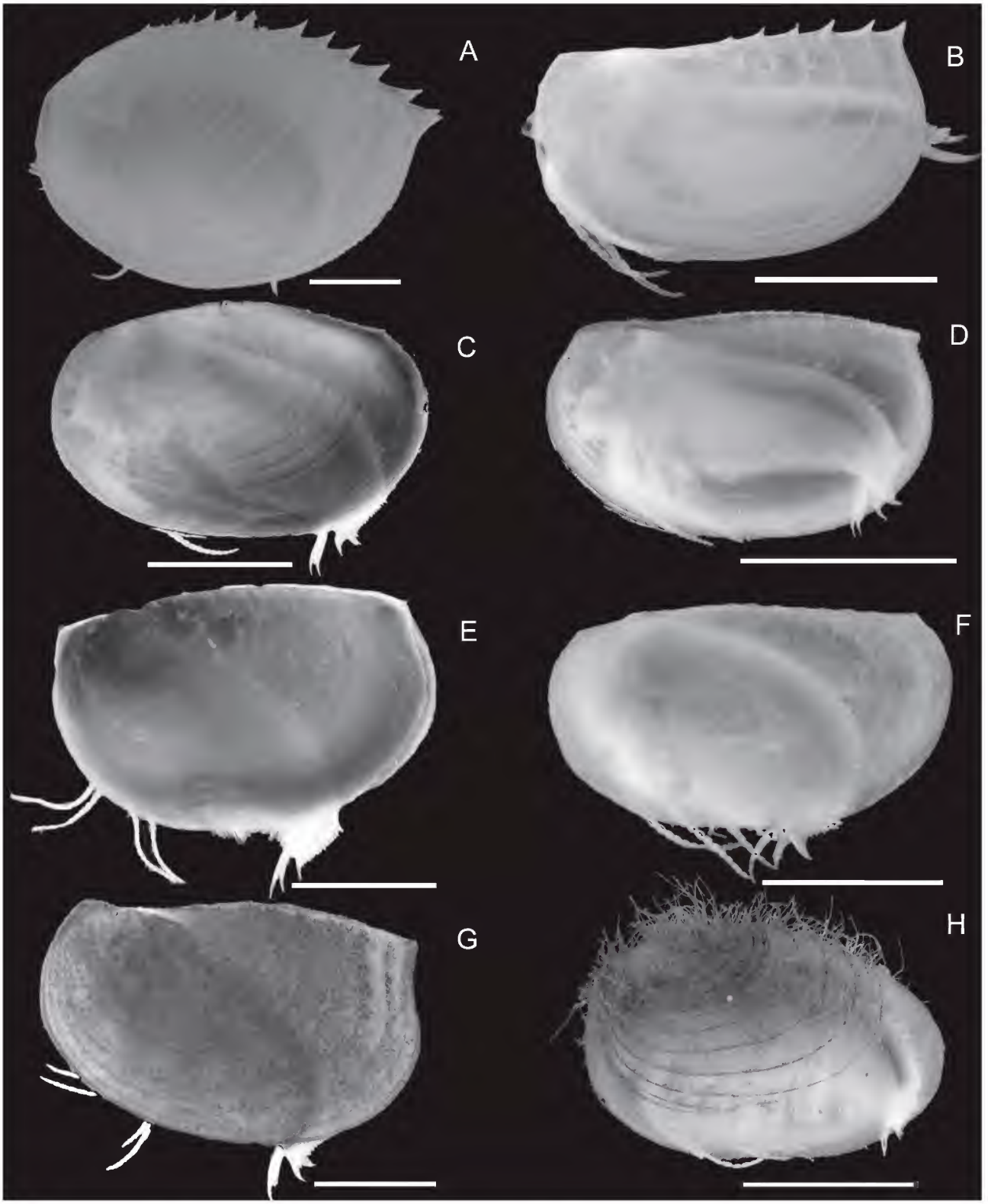

Fig. 2. Photographs of whole specimens of species of *Limnadopsis*. (*A*) *L. birchii*; (*B*) *L. tatei*; (*C*) *L. parvispinus*; (*D*) *L. minuta*; (*E*) *L. multilineata*; (*F*) *L. occidentalis*; (*G*) *L. paradoxa*; (*H*) *L. pilbarensis*. Scale bars 5 mm.

and only two lobes on the first antennae. Finally, and first introduced in the generic key provided by Richter & Timms (2005), all species of *Limnadopsis* have spines on the tip of the movable finger of the clasper, not a sucker as in other species of Limnadiidae. This unique character, together with the large and protruding first spine of the telson spine rows can be used to diagnose the genus, with limited reference as well to the numerous well-marked growth lines and dorsal carinae, The general appearance of specimens of *Limnadopsis* is shown in Figs. 1, 2.

Species descriptions

Limnadopsis birchii (Baird, 1860)

Figs. 2A, 3, 4A, 5A,B

Estheria birchii Baird, 1860: 392–393, pl. 72, fig. 1a–e; Grube, 1865: 234 (list); Simon, 1886: 453 (list).
Limnadopsis squirei Spencer & Hall, 1896: 239–241, pl. 21, fig. 15, pl. 22, figs. 16–19; Wolf, 1911: 254 (list); Dakin, 1914: 295 (list); Henry, 1924: 132 (key).
Limnadopsis birchii.—Sayce, 1903: 249–250; Wolf, 1911: 254 (list); Dakin, 1914: 295 (list); Henry, 1924: 121–122 (list), 132; Brtek, 1997: 58 (list); Richter & Timms, 2005: 349.
Limnadiopsis brichii.—Daday, 1925: 177–181, fig. 122 (misspelling); Novojilov, 1958: 104–105, fig. 13 (misspelling).

Types. None designated or available, but some material available for *L. squirei*.

Remarks on type material. Baird's (1860) material cannot be located, but some of the original material used by Spencer & Hall (1896) for their description of *L. squirei* (reported by the authors to comprise six specimens in spirit and over a 100 dried carapaces) is available. The NMV has four of the dried carapaces from central Australia which I regard as syntypes (NMV J53349), and also a few specimens in alcohol (NMV J54042), but there is uncertainly over the latter's origin so I do not treat them as syntypes.

Other material. New South Wales: 2♂, 1♀, NW of Bourke, Tredega Station, Lake Muella, 29°31'S 144°53'E, 6.xii.1999, B.V. Timms, AM P76800; 1♂, 12♀, NW of Bourke, Bloodwood Station, Last Swamp, 29°29'S. 144°49'E, 6.ii.1999, B.V. Timms, AM P76801; 5 empty carapaces, 130 km NW of Bourke, Bloodwood Station, 29.6°S 144.9°E, 26.vi.1999, S. Richter, AM P55649; 4♂, 7♀, 11 km N of White Cliffs, 30.7°S 143.1°E, no date, A.B. Chislett, AM P11456, 8♂, 5♀, W of Cooma, Coolringdon Station, Fat Hen Lake, 36°16'S 148°56'E, 19.iv.1992. B.V. Timms AM P76802. **Queensland**: near Windorah, Carranya Station, claypan, 25°18'S 142°12'E, 6.iii.1977, J. Covacevich, QM W7254; near Roma, Suva Station, Bore Hole, 26°21'S 148°28'E, 6.iii.1977, J. Covacevich, QM W10953; 2♂, E of Thargomindah, Bindegolly Lake, 28°04'S 144°10'E, 9.ii.2007, M. Handley, QM W28364; 7♂, 14♀, Cunnamulla, 28.1°S 145.7°E, iii.1947, N. Geary, AM P11794; 16 individuals, near Hungerford, Currawinya National Park, between Lakes Yumberarra and South Kaponyee, creek pool, 28°53'S 144°20'E, 7.xii.1999, B.V. Timms, QM W28365; 4♂, near Hungerford, Currawinya National Park, Lake South Kaponyee, 28°52'S 144°20'E, 7.xii.1999, B.V. Timms, QM W28366; 23 individuals, near Hungerford, Currawinya National Park, "CA" clay pan, 28°52'S 144°20'E, 3.ii.1998, B.V. Timms, QM W28368; 1♀, SW of Diranbandi, Culgoa Floodplain National Park, East Burrenbah Section, 28°51'S 146°48'E, 14.xii.1999, C. Eddie, QM W28368. **Northern Territory**: 1♂, 10♀, 3 empty carapaces, Tanami Desert Sanctuary, east of Mount Ptilotus, claypan, 20°12'S 130°12'E, no date, H. Cogger, AM P14934. **South Australia**: 1♂, 2♀, N of Oodnadatta, Hamilton Station, 17.iii.1976, Mr Cekic, SAM C6353; N of Oodnadatta, Stevenson Ck, no date but earlier than 1897, Prof Spencer, NMV J54042; N of Oodnadatta, Macumba Ck, no details, NMV J53361; Macumba & Stevenson Cks, Spencer & Hall?, NMV J53995; Cameron Corner, cane grass swamp, 22.iv.1979, M.G. & A.H. Corrick, NMV J54001; 4♂, one indeterminate individual, near South Gap homestead, South Gap Creek, i.2007, J & K Sanderson, SAM C3652. **Western Australia**: Upper

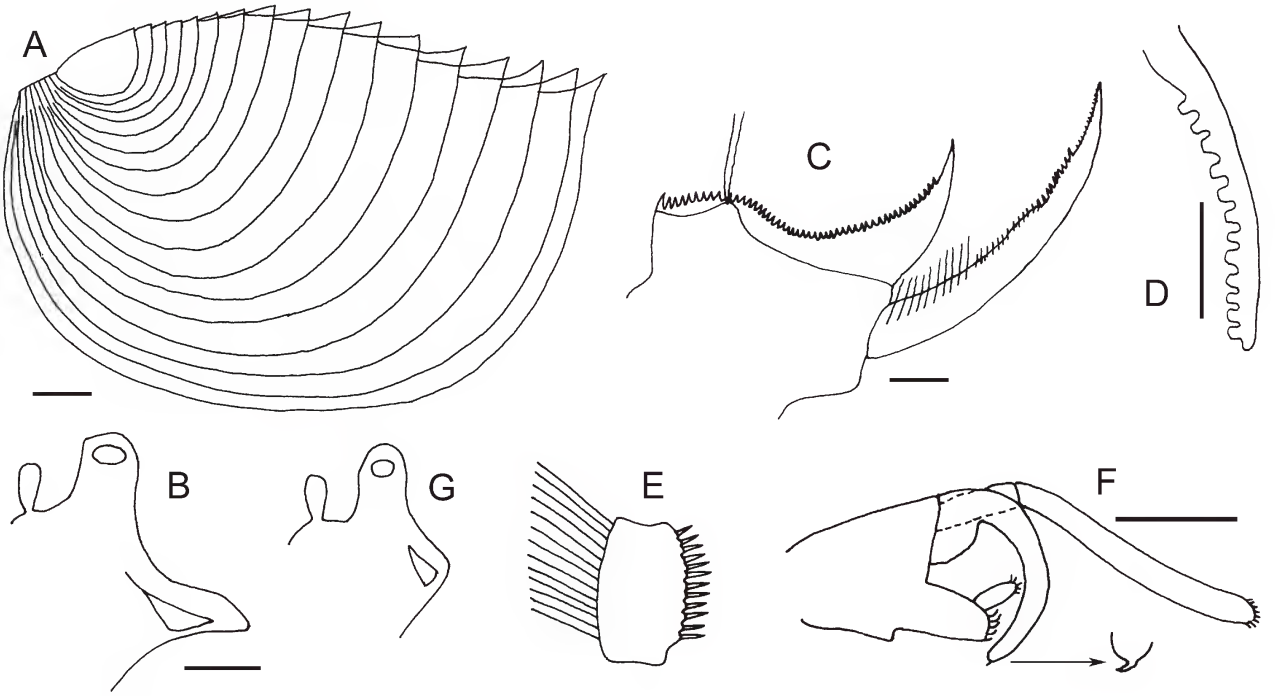

Fig. 3. *Limnadopsis birchii* (Baird), Bloodwood Station, via Bourke, NSW. Male: (*A*) carapace; (*B*) head; (*C*) telson; (*D*) antennule; (*E*) a middle flagellomere of second antenna; (*F*) second clasper. Female: (*G*) head. For clarity some growth lines of the carapace are incompletely shown anterior to umbo. Scale bars 1 mm.

Fortescue River, Mulga Downs Station, near Bunji Well, muddy pool, 22°10'S 118°26'E, 3.vii.1970, M.H. Shepherd, WAM C39325; Barrow Is., 20°52'S 115°24'E, 18.iv.1976, C. Butler, WAM C39326; near Leinster, mine site, waterhole in dry creek bed, 20.iii.2001, G. Walker, WAM C28201; 120 km NNE of Broome, "Bungnaduk", 8.ii.1989, J. Martin, WAM C39327; 1♀, NE of Carnarvon, Mardathuna Station, Bulgra pool, 24°24'S 114°33'E, 21.iii.1995, S.A. Halse, WAM C39328; 1♂, 7♀, NE of Carnarvon, Cooralya Station, Bluebush Bore Swamp, 24°28'S 114°18'E, 21.iii.1995, S.A. Halse, WAM C39329; 3♀, near Laverton, 22 km northwest on highway, samphire swamp, 28°36'S 122°13'E, 17.ii.2003, B. Datson, WAM C39330.

Distribution. Australia-wide (but not recorded from Victoria or Tasmania), generally in the arid and semiarid inland.

Comments. This large distinctive species was first described by Baird in 1860 as *Estheria birchii* on the basis of a female collected in floodplain lagoons of the Namoi (misspelt Wamoi) River, NSW. The description is poor, but there is no doubt that what is today known as *L. birchii* was the subject. In 1896 Spencer and Hall published a detailed description of a species from central Australia that they placed in a new genus and called *Limnadopsis squirei*. Sayce (1903) realized that Baird's *E. birchii* and the new *L. squirei* were synonymous. Since then, many authors (see synonymy list above) have mentioned the species, perhaps with new distribution records, but without adding to its known features.

Spencer & Hall's (1896) description is almost adequate, but it lacks a description of the thoracopods. The thoracopods of basic structure noted for spinicaudatans (McLaughlin, 1980; Alonso, 1996; Ferreri & Grygier, 2003). The male third thoracopod (Fig. 4A) with five endites on medial surface, each with differing numbers of setae (Ist with c. 20; 2nd with c. 40; 3rd with c. 30, 4th with c. 30; 5th with c. 25). These setae not evenly distributed but sparse in middle region of the endite and crowded at proximal end, more so on the 4th and 5th endites than on others. Fifth endite elongated, and similar in shape to finger-like endopod. Fifth endite bearing a one-segmented palp slightly longer than endite. Exopod bipolar with finger-like extensions distally (termed a flabellum by McLaughlin, 1980) and proximally. Endopod clothed with c. 60 setae and exopod with more than 100 setae. All setae two-segmented and differing slightly as to degree of feathering—exopod and endopod setae fully feathered, most endite setae with proximal segment sparsely feathered and distal segment densely feathered, and setae of the 5th endite naked. Oval-shaped, naked epipodite lying between proximal lobe of exopod and the main axis carrying endites. Other thoracopods essentially similar to third, but without palp on 5th endite and with slightly differing proportions of parts, particularly of epipodite. Female thoracopods similar to those of males but without palp on 5th endite, and ninth and tenth pairs with projections of exopod on which eggs carried.

Eggs (Fig. 5A,B) round, about 172 μm in diameter (range 162–186 μm, n = 10), with parallel groups of ridges and deep clefts arranged around surface. No major differences in this respect between eastern and western populations (Fig. 5A,B) studied.

Variability. *Limnadopsis birchii* is more variable than indicated by Spencer & Hall (1896). The carapace shape (Figs. 2A, 3A) is broadly oval, but usually with a distinct anterodorsal angle of about 120°, and a convex dorsal margin that is slightly depressed anterior of the umbo. The dorsal margin, posterior of the embryonic valve, bears many asymmetrical carinae (= "backwardly directed serrations" of Spencer & Hall 1896), the posterior edges of which are

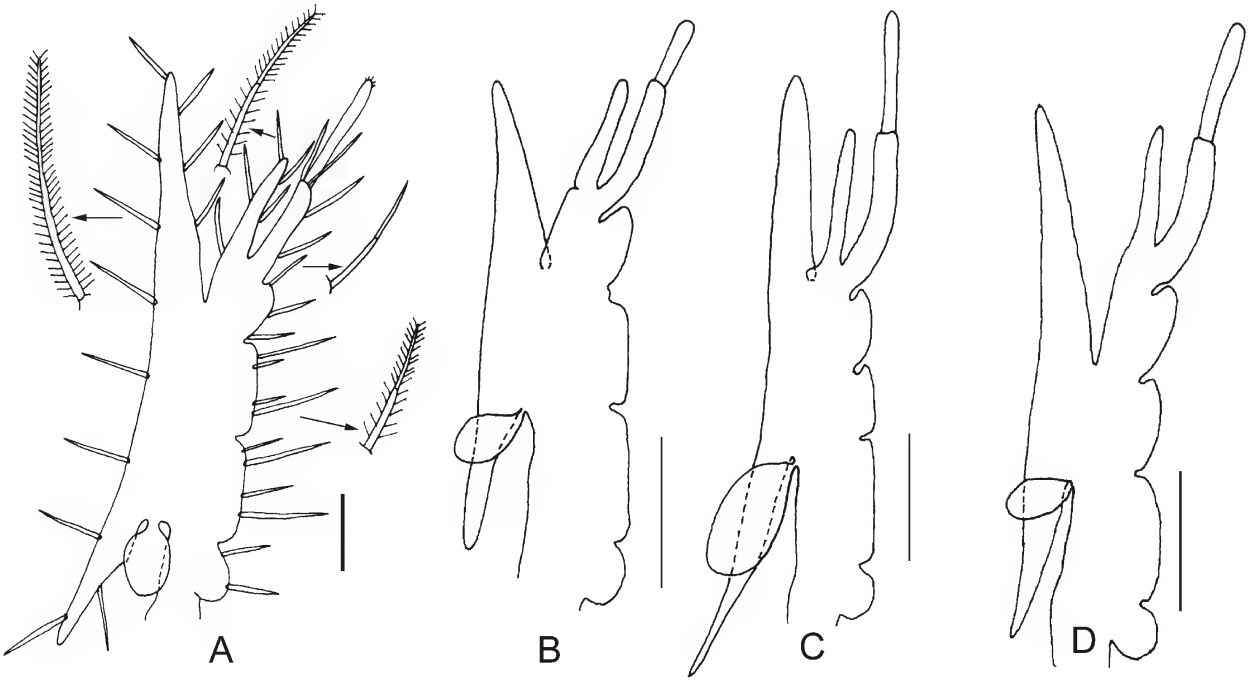

Fig. 4. Third thoracopods of males of (*A*) *L. birchii*; (*B*) *L. tatei*; (*C*) *L. parvispinus*; and (*D*) *L. paradoxa* n.sp. A few of the numerous setae (see text), and details of the major types of setae are shown only for *L. birchii*. Scale bars 1 mm.

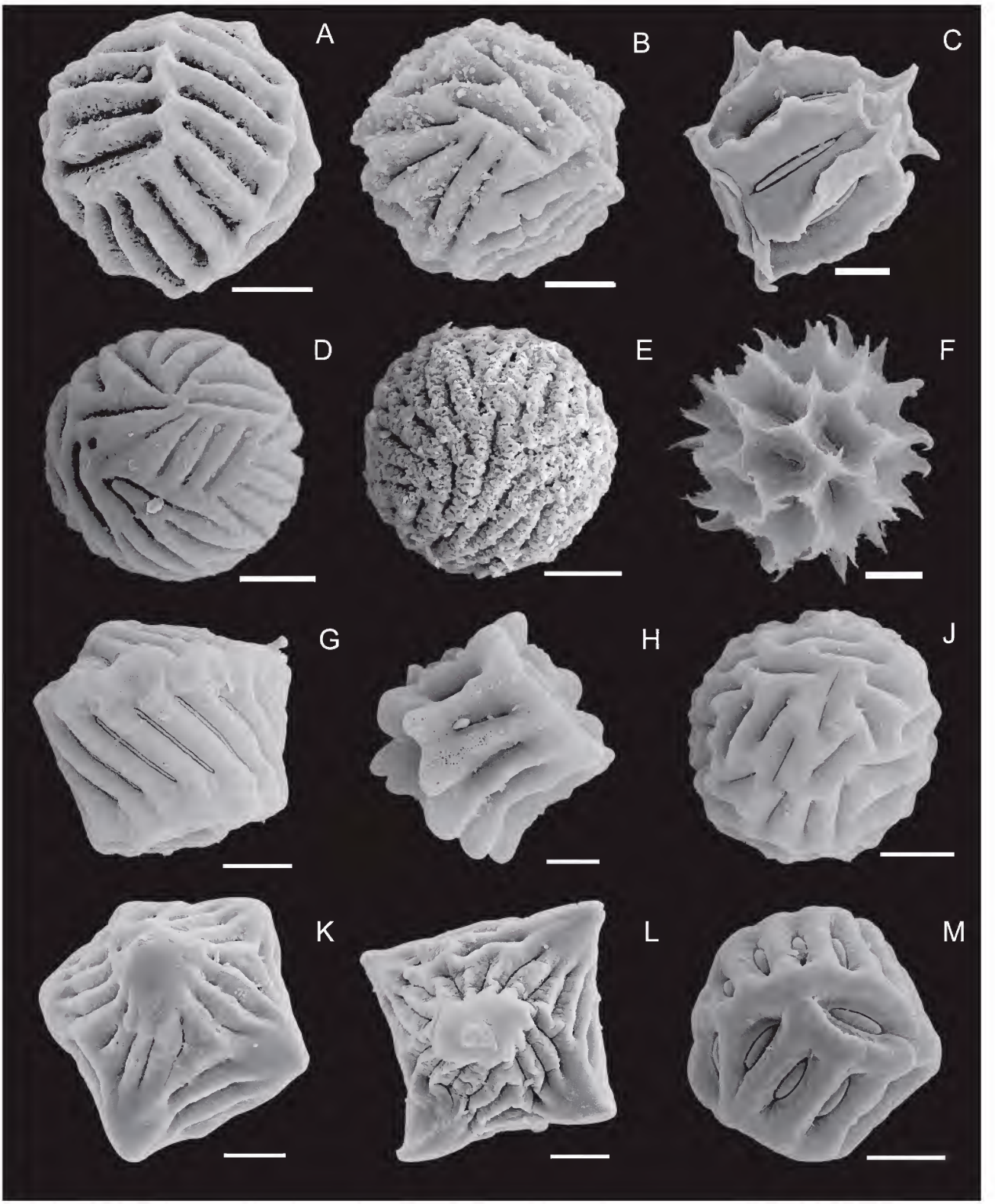

Fig. 5. SEMs of eggs. (*A*) *Limnadopsis birchii*, Twin Pans, Currawinya National Park, Qld; (*B*) *L. birchii*, Bluebush Bore Swamp, via Carnarvon, WA; (*C*) *L. multilineata*, Mitchell River Falls, Kimberley, WA; (*D*) *L. tatei*, Bloodwood Station, Paroo; (*E*) *L. tatei*, near Laverton, WA; (*F*) *L. pilbarensis*, Chichester Range, WA; (*G*) *L. parvispinus*, Bloodwood Station, via Bourke, NSW; (*H*) *L. parvispinus*, Coolringdon Station, via Cooma, NSW; (*J*) *L. occidentalis*, Boolathana Station, via Carnarvon, WA; (*K*) *L. paradoxa*, Sieda Farm, Grass Patch, WA; (*L*) *L. paradoxa*, East Lake Bryde, via Newdegate, WA; (*M*) *L. minuta*, Keep River National Park, NT. Scale bars 50 µm.

continuous with the growth lines, and which increase in size posteriorly till the last one (usually) protrudes beyond the posterodorsal corner. In many populations and individuals, however, these outgrowths are irregular and in some cases absent altogether. Similar carinae exist in *L. tatei*, but it is distinctive of *L. birchii* that invariably the protrusion of each carinae beyond the hinge line begins well forward in the previous growth area, almost back to the second preceding growth line. Generally there are about 12–13 growth lines, with a range of 11–15 mentioned by Spencer & Hall (1896), and 10–17 in the present material examined. Enormous carapace sizes of up to 27 mm long and 20 mm high were mentioned by Spencer & Hall (1896); slightly larger ones (to 29 mm) were observed in the present material and also relatively small ones of 18 mm (apparently adults). The length:depth (L:D) ratio is usually c. 1.5. Often females are slightly bigger than males, but otherwise both sexes are similarly shaped.

Spencer & Hall's (1896) description of the head and rostrum (Fig. 3B) is a little different from that observed in the present material. While in males, the rostrum is at right angles to, and anterior of the ocular tubercle, there is no sharp angle in the cephalic profile between them, as in most other species of *Limnadopsis*, but an even curvature. The rostrum is generally about equal in length and basal width, and its apex is rounded and slightly curved ventrally. In females the rostrum (Fig. 3G) is shaped like an isosceles triangle with its short axis at right angles to the head. The ocular tubercle is typically longer than wide, a shape not observed in other species of *Limnadopsis*.

The first antenna was well characterized by Spencer & Hall (1896). In males it is longer than the peduncle of the second antenna, and in females equally as long as the latter. Spencer & Hall (1896) mentioned 16 lobules in males, but the mean in the present material is 12 (Fig. 3D), with a range of 10–15. The second antennae are essentially as described by Spencer & Hall (1896), with a peduncle of 11 segments (12 in most of the present material), and 2 flagellae of about 18 flagellomeres each. Most noticeable in the present material is the large number (ca 12) of dorsal spines on most of these flagellomeres (Fig. 3E), compared to fewer than 10 in other species of *Limnadopsis*.

All specimens have 32 pairs of thoracopods, 6–8 more than in other species of *Limnadopsis*. The dorsoposterior armature on the most posterior thoracic segments, not recorded by Spencer & Hall (1896), is variable but generally consists of 3–5 spines each on the last 7–9 segments, these being preceded by 2–3 segments with both a few spines and a few setae, then another 7–10 segments with setae, the number of which decreases anteriorly in number from about 10 per segment in females, and about 5 in males, to single one. The claspers of the male (Fig. 3F) are of standard spinicaudatan structure (Fryer, 1987), with almost no macroscopic variation between populations. The asymmetrical protrusion on the anterior surface of the hand is relatively small and on the hand's proximal half. The spine on the apex of the movable finger may be single and stout, or multiple (2–4) and thin; the palp of the movable finger in the second clasper is longer than usual, being at least 1.75 to 2 times the length of the hand. Concerning the telson (Fig. 3C), Spencer & Hall (1896) mentioned that there are about 50 dorsal spines (= denticles) in each row (cf. their fig. 19), and a pair of telsonic filaments at about one quarter of its length. They described the dorsal surface curved to form a shallow S-bend, and a curved, movable caudal claw bearing a "large number of plumose setae" proximally with the distal part the dorsal edge finely setose. In the present material the mean number of dorsal telson spines in each row is indeed about 50 (range 48–55), but rarely do they increase in size posteriorly as Spencer & Hall (1896) claimed. This number is more than twice that of other species of *Limnadopsis*; furthermore the most anterior spine is little bigger than the next few, as opposed to the situation in most other species of *Limnadopsis* in which it is at least 1.5 times larger. The shallow S-bend (convex anteriorly, concave posteriorly) of the dorsal surface of the telson is present in most specimens examined, but in some the dorsal surface is almost straight. The caudal claw is evenly curved, i.e. the proximal portion is not straight as in most other species of *Limnadopsis*. It bears about 10–12 long setae (longer than width of the claw), followed in sequence by about 12–15 spines on the middle section of the caudal claw, and then the fine denticles of Spencer & Hall (1896) on the distal quarter. The most distal of the spines is almost always the largest and thickest.

Limnadopsis tatei Spencer & Hall, 1896

Figs. 2B, 4B, 5D,E, 6, 7

Limnadopsis tatei Spencer & Hall, 1896: 241, figs. 20–27; Sayce, 1903: 250; Wolf, 1911: 254 (list); Dakin, 1914: 295 (list); Henry, 1924: 122 (list), 132 (key); Richter & Timms, 2005: 349.

Limnadiopsis tatei.—Daday, 1925: 181–183, fig. 123 (misspelling of the genus name).

Limnadiopsium tatei.—Novojilov, 1958: 104, fig. 12; Brtek, 1997: 58 (list).

Types. Originally no types designated. Now a neotype (♂) has been chosen (NMV J54053).

Comments on types. The neotype is thought to be from Professor Spencer's original collection from Central Australia. Certainly its characteristics agree with the limited original description.The exact location of the type locality is unknown and even the date is not in museum records, but it is believed to be 1896. Given that this species is widespread and variable (see later), it is helpful to have a neotype taken from the type locality, illdefined as it is.

Material. **New South Wales**: 9♂, 16♀, NW of Bourke, Bloodwood Station, Shining Box Pool, 29°27'S 144°50'E, 24.v.2000, B.V. Timms, AM P76803; 6 specimens, 140 km NW of Bourke, Tredega Station, Johnsons Tank, 29°30'S 144°54'E, 26.i.1995, B.V. Timms, AM P47127. **Queensland**: 3♂, 1♀, E of Thargomindah, Bindegolly National Park, Lake Hutchinson, 1.ii.2006; 27°55'S 144°13'E, M. Handley; QM W28369; 1♂, E of Thargomindah, Bindegolly National Park, Lake Toomaroo, 17.i.2007; 27°59'S 144°12'E, M. Handley; QM W28370; 1♂, E of Thargomindah, Bindegolly National Park, Lake Bindegolly, 9.ii.2007; 28°04'S 144°12'E, M. Handley; QM W28371; 18 individuals, SW of Cunnamulla, Rockwell Station, grassy pool S of North Blue Lake, 28°51'S 144°58'E, 9.vi.2007, B.V. Timms, QM W28372; 69 individuals, near Hungerford, Currawinya National Park, the Yapunyah Swamp, 25°30'S 144°18'E, 18.v.1996, B.V. Timms, AM P47948; 5♀, near Hungerford, Currawinya

National Park, Killambirdie Waterhole, 25°48'S 144° 30'E, 8.v.1996; B.V. Timms, AM P55618. **Central Australia**: 2♂, no details, Prof Spencer, NMV J54043; 1♂, Onkaparinga Ck, no details, Prof Spencer, NMV J54053. **South Australia**: 3♂, 1♀, Olympic Dam, 30°28'S 136°44'E, 12.ii.1981, M.J. Tyler, SAM C6347; 1♀, Olympic Dam, 44 km east, 30°28'S 136°45'E, 12.ii.1987, M.J. Tyler, SAM C6348; 3♂, 3♀, Olympic Dam, 8 km on track to Lake Blanche, a samphire swamp, 30°29'S 136°48'E, M.J. Tyler, SAM C6349; 2♂, Roxby Downs, 30°42'S 136°46'E, M.C. Geddes, SAM C6350; 3♂, 96km N of Port Augusta, M. Wickstein, ii.1962, SAM C6354. **Western Australia**: Gascoyne District, Landor Station, pool near homestead, no date or collector, WAM C3485; 11 km S of Wittenoon, pools at head of Joffie Falls, 22°23'S 118°16'E, 12.vi.1970, M. Shepherd, WAM C39331; near Yalgoo, 5.x.26, J. Clark, NMV J43991; 10♂, 10♀, W of Cue, Austin Downs Station, swamp near homestead, 31.viii.2004, 27°23'S 117°45'E, B.V. Timms, WAM C39332; c. 35 individuals, near Laverton, roadside swamp 20 km west, 28°36'S 122°13'E, 22–1–2007, B.V. Timms, WAM C39333.

Distribution. Australia-wide, mainly in the central and northern inland. It is not recorded from southern NSW, Victoria, Tasmania, southern SA, or southern WA.

Description of neotype. Carapace (Fig. 6A) 12 mm by 7.6 mm, L:D ratio c. 1.6. Dorsal margin weakly curved convexly, with anterior portion depressed at umbo and slightly upturned towards dorsoanterior corner. Ten robust growth lines. Carapace dorsal surface with each growth line extended as carina. Carinae posterior to umbo large and asymmetrical and directed posteriorly, but those anterior to umbo the carinae minor and constituting small, anteriorly-facing steps in the dorsal line. Each carinae wholly contained within a single growth zone. Umbo area slightly widened anterolaterally. Carapace surface texture granular.

Head (Fig. 6B) with pyriform frontal organ situated posteriorly, preceded by a rounded ocular tubercle, and rostrum orientated at right angle to head. Rostrum length about 1.5 times its basal width; apex rounded and slightly bent posteriorly and base containing triangular naupliar eye dipping obliquely with respect to rostrum axis and occupying much of its basal area.

First antenna a little longer than second antenna peduncle, with 10 subequal lobes. Second antenna with two flagellae, each composed of about 15 beaded flagellomeres, these of variable length but generally longer and thicker proximally. Most of middle flagellomeres with 5–7 spines laterally, with no apical grouping.

Trunk segments 26. Posteriormost segment with spineless dorsal protuberance, preceding 7 segments each with 1–3 spines its protuberance; next more anterior 6 segments with long setae varying in number from many posteriorly to 1–2 on more anterior segments (Fig. 6C). Hand of claspers (Fig. 6D) with asymmetrical outgrowth on anterior edge of basal half. Immovable finger with numerous spines apically:

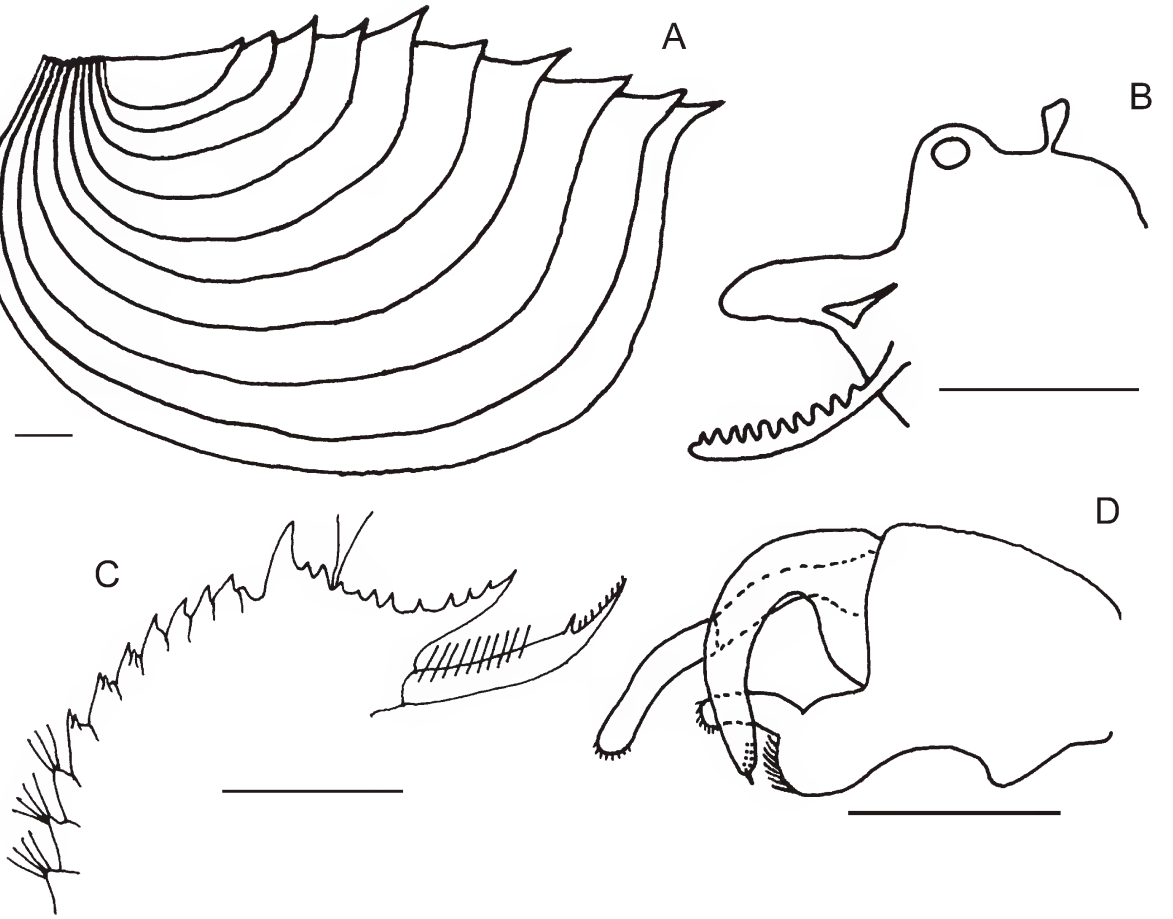

Fig. 6. *Limnadopsis tatei* Spencer & Hall, lectotype, central Australia. Male: (*A*) carapace; (*B*) head; (*C*) telson and dorsoposterior surface of trunk; (*D*) second clasper. Scale bars 1 mm.

central ones short and stout, but these changing to long, thin curved spines on inner edge. Palp of movable finger short with hair setae apically. Base of movable finger broad, supporting posteriorly an evenly curved finger terminating in a small spine. Palp two-segmented, as long as hand in the first clasper and about half as long again in second clasper. Distal segment bearing many short hair setae apically. No setae on junction of two palp segments.

Third thoracopod (Fig. 4B) similar in structure to that of *L. birchii* (Fig. 4A). Proportions of endites, endopod, exopod and epipodite slightly different, and significantly palp of the fifth endite only about half its length. Other thoracopods of same basic structure, but without palp and generally epipodite larger.

Telson (Fig. 6C) armed with 11 spines in each row, spaced unevenly and of various widths and lengths. Anterior spine about three times as large as the others and curving slightly posteriorly; posterior spine with posteriormost 3 telsonic spines on its anterior surface, curved anteriorly and more than twice as long as wide at the base. Two telsonic setae inserted on protuberance about one third of way along dorsal margin of telson. Caudal claws well developed, more than twice as large as posterior telsonic spine and unevenly curved concavely forward. Basal half thick, almost straight, and bearing about 10 shortish hair setae mesodorsally. Short spine about two-thirds of way along the claw on dorsal surface, followed by row of many denticles dorsally on pointed apex of claw.

There are no females in the original collection by Prof. Spencer, so no description of a female *L. tatei* is available.

Variability. As noted by Spencer & Hall (1896), the carapace of males varies in the shape of its dorsal outline from straight, as in the Austin Downs specimens (Fig. 7A) to slightly convex as in the neotype (Fig. 6A). Further variability is seen in size of adult male carapaces (9–13 mm long), the number of growth lines (7–11), and the development of the dorsal spines. The latter range from being almost absent, as in the specimens from Yalgoo, to well developed as in most specimens seen. The male rostrum (Fig. 7B) is often relatively longer than in the neotype, reaching twice its basal width and the degree of rounding and posterior bending very variable. First antennal lobules usually range from 8–10 and antennal segments from 12–16; both were often observed to be damaged and missing parts. Most specimens have 26 body segments, but a few have only 25. Major variability in the telson (Figs. 6C, 7C,H) includes the number of dorsal spines, ranging from 9–13, caudal claw setae varying from 8–12, and spines varying from 1–3, more often three than the one of the neotype. The anteriormost dorsal spine is always at least twice the size of other such spines, and often even larger, as in the neotype.

Females are similar to males (Fig. 7F–H), as was first noted by Spencer & Hall (1896). They noted that the dorsal margin of the carapace is distinctly more convex in the female, the rostrum is shorter, and there are fewer lobules

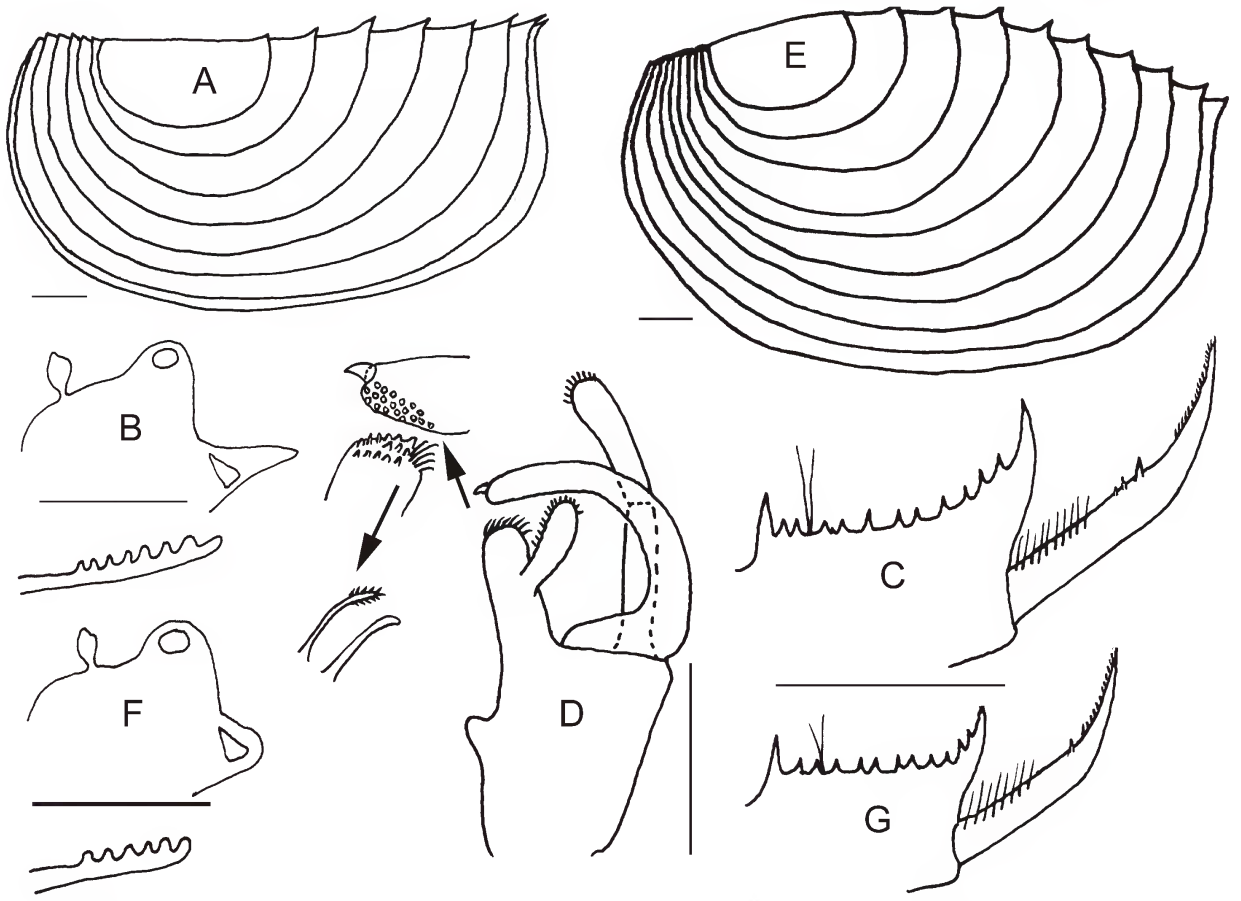

Fig. 7. *Limnadopsis tatei* Spencer & Hall, Austin Downs, via Cue, WA. Male: (*A*) carapace; (*B*) head and antenna 1; (*C*) telson; (*D*) second clasper with some details. Female: (*E*) carapace; (*F*) head and antenna 1; (*G*) telson. Scale bars 1 mm.

in the antennule than in the male. In the present material, the rostrum is as long as deep and there are about 6–8 lobules in the first antenna while the flagellomeres of the second antenna usually numbering 12–15; both figures are a little less than those of males. Number of body segments, posterodorsal armature, and the telson are similar to those in males.

Eggs. Eggs are different in the eastern and western populations studied (Fig. 3D,E). In both they are round and about 150 µm in diameter (range 144–171 µm, n = 10), and the surface has numerous straight furrows not as wide or deep as in *L. birchii*. In the western population the intervening ridges are sharper and the furrows tend to be short and arranged in short, nested Vs of 2–3 furrows, while in the eastern population, the ridges are frilly, longer and more randomly arranged. The significance of these different egg sculpturings is unknown; the eggs could be variable as in *L. parvispinus* (see later), or the differences could indicate separate species in the east and west. The later possibility is not supported by any consistent differences in the morphology of the adults.

Comment. Novojilov (1958) transferred *Limnodopsis tatei* into a new genus *Limnadiopsium* which has not been followed here (see later).

Limnadopsis parvispinus Henry, 1924

Figs. 2C, 4C, 5G,H, 8, 9

Limnadopsis parvispinus Henry, 1924: 121 (list), 132 (key), 132–133, pl. 32, figs. 1–7; Brtek, 1997: 58 (list); Richter & Timms, 2005: 349.

Types. Syntypes (3 ♂, 9 ♀) in AM G5524 and G5226.

Comment on types. The syntypes are from two different localities about 305 km apart. The inaccurate (see below) original description seems to be based on all specimens, and given the variability in this species (see below), it was decided not to choose a lectotype from a particular locality because this may jeopardize future detailed work on this species/species complex.

Material. **New South Wales**: 10♂, 10♀, 180 km NW of Bourke, Brindingabba-Willara Crossing Road, 29.3°S 144.7°E, 9.iii.1995, B.V. Timms, AM P47126; 6♂, 3♀, NW of Bourke, Bloodwood Station, Lower Crescent pool on Bell Ck, 29°32'S 144°52'E, 10.vi.1998; B.V. Timms, AM P76804; 1♂, 4♀, NW of Bourke, Bloodwood Station, Marsilea Pool, 29°33'S 144°52'E, 7.xii.1999, B.V. Timms, AM P76805; 10♂, 15♀, NW of Bourke, Tredega Station, Johnsons Tank, 29.5°S 144.9°E, 26.i.1995, B.V. Timms, AM P47124; 3♂, 9♀, NW of Bourke, Tredega Station, Johnsons Tank, 29.5°S 144.9°E, 10.iii.1995, B.V. Timms, AM P47125; 2♂, 4♀, NW of Bourke, Muella Station, vegetated pool no. 3 near homestead, 29°31'S 144°56'E, 7.xii.1999; B.V.

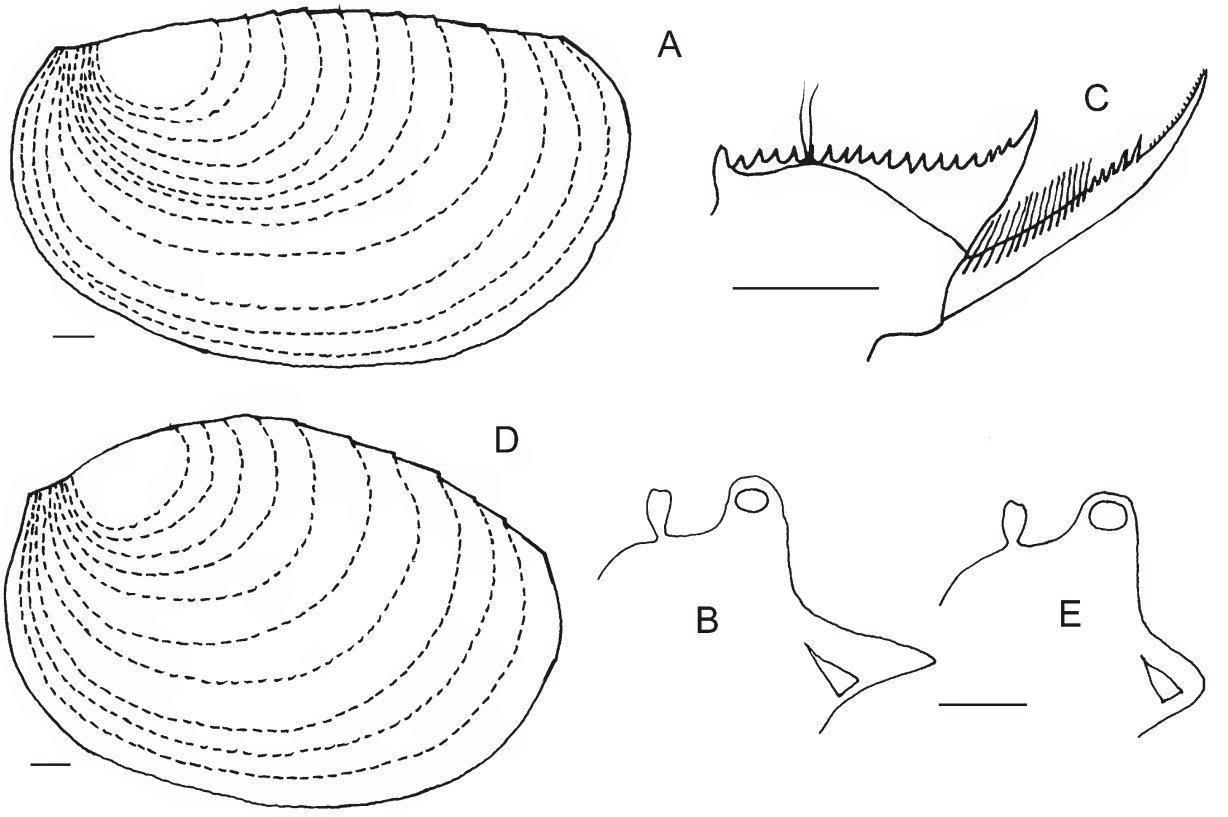

Fig. 8. *Limnadopsis parvispinus* Henry, syntypes, Mossgiel, NSW. (*A*) male carapace; (*B*) male head; (*C*) male telson; (*D*) female carapace; (*E*) female head. Scale bars 1 mm.

Timms, AM P76806; 1♀, near Trangie, Old Cathundral, 31°55'S 147°50'E, 12.ii.1941, W.R.G. Officer; 1♂, 6♀, Griffith District, Rice Bay, 34.3°S 146.0°E, 15.xi.1979, E.L. Jones, AM P53290; 13♂, 8♀, no data, P6788; 6♀, SW of Ivanhoe, Mossgiel, 33°12'S 144°36'E, no date, H.K. Bennett, AM G 5224; 3♂, 3♀, NW of Cootamundra, Bland district, 34°18'S 147°48'E, no date or collector, AM G5226; 42 individuals, W of Cooma, Coolringdon Station, Fat Hen Lake, 36°16'S 148°56'E, 19.iv.1992. B.V. Timms, AM P76807. **Queensland**: 12 individuals, S of Bollon, Bendee Station, a clearwater lake, 28°12'10"S 146°43'35"E, 23.iv.2004, S. Peck, QM W28373; 11 individuals, SW of Cunnamulla, Rockwell Station, Buster Black Box Swamp, 28°48'S 145°02'E, 9.xii.1999; B.V. Timms, QM W28374.

Distribution. Inland NSW and southern inland QLD, but could be further north, west, and south of this area.

Comments. Henry's (1924) account is sufficient to identify the species, but is inadequate on details and contains some significant inaccuracies. One of these is the claim that there are about 30 pairs of thoracopods whereas there are 25–26, and another is a supposed series of spines on the basal three-quarters of the caudal claw, whereas there is actually a mixture of a few spines apically and many setae basally. Furthermore, Henry (1924) wrote that the "the end claws are not so strongly armed" in females, whereas little difference from the situation in males, or the opposite, was observed in the syntypes. The species is redescribed below, on the basis of the syntypes.

Redescription. *Male*: Carapace (Fig. 8A) oval, generally about 15 mm long and 9 mm, L:D ratio of 1.66. Dorsal margin weakly convex and with slight depression anterior to weakly developed umbo. Both dorsoanterior and dorsoposterior angles indistinct, and anterior carapace, and particularly the posterior carapace, protruding and strongly but unevenly convex. Ventral edge weakly and evenly convex. Dorsal margin almost smooth, though with some slight serrations at posterior growth lines. Growth lines 11–12, typically weakly developed. Carapace weakly granulated within, but with smooth, somewhat lustrous, surface.

Head (Fig. 8B) with pyriform frontal organ situated posteriorly and about as high as eye mound Anterior side of eye mound and rostrum meeting at about 120°, junction evenly curved. Rostrum triangular, about 1.5 times longer than its basal width, with apex narrowly rounded and naupliar eye situated basally with its axis tipped about 45° ventrally to that of rostrum. First antenna subequal in length to peduncle of second antenna and with about 9 lobules. Second antenna with peduncle of about 12 apparent segments and flagella with 16–18 flagellomeres. Spination of middle flagellomeres variable, ranging from 4–7 spines and sometimes with two grouped apically.

Trunk segments usually 25, occasionally 26, each bearing pair of thoracopods, these decreasing in size posteriorly with anterior two modified as claspers. Posterodorsal armature with 1–3 spines on small protuberances on each of last 6–7 segments and a few setae on 4–6 segments anterior to these. Claspers of normal *Limnadopsis* structure, but with 1–3 spines apically on movable finger and prominent protrusion

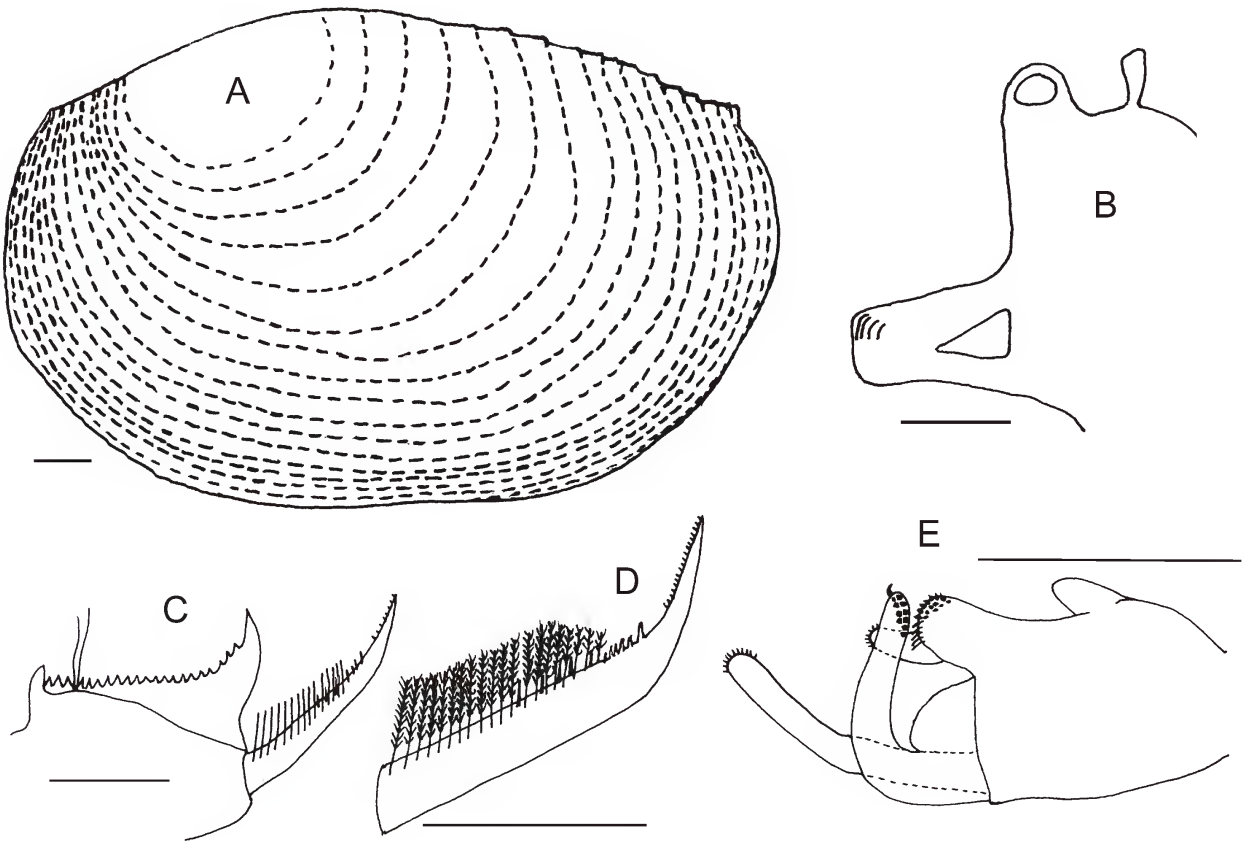

Fig. 9. *Limnadopsis parvispinus* Henry, Bollon, Qld. Male: (*A*) carapace; (*B*) head; (*C*) telson; (*D*) cercopod; (*E*) clasper. Scale bars 1 mm.

midway on the anterior edge of hand. Third thoracopod (Fig. 4C) similar in structure to that of *L. birchii*. Proportions of endites, endopod, exopod and epipodite slightly different, and significantly palp of fifth endite slightly shorter than fifth endite and epipodite proportionally larger. Other thoracopods of same basic structure, but without palp and with even larger epipodite.

Telson (Fig. 8C) with 18 dorsal spines in each row. Most anterior spine about 1.25 times larger than next few. Most spines subequal in size and evenly spaced, though most posterior ones smaller and crowded on fixed telsonic claw. Two telsonic setae inserted on protuberance situated about one quarter of way along dorsal margin of telson. Caudal claws about 8–10 times longer than wide, with long, almost straight basal section of fairly even width and much shorter, curved apical part narrowing to sharp apex. Basally each caudal claw bearing about 15 setae mediodorsally, most slightly longer than width of claw, followed by about 6 short spines almost dorsally, last of these being largest. First few spines sometimes arising from between last few setae. Curved apical part beyond last spine bearing many short denticles dorsally.

Female. Carapace (Fig. 8D) similar to that of male, but more compact (length 13–14 mm, height 9–9.5 mm) and with more convex dorsal and ventral margins. Depression anterior to umbo hardly present or not at all. Growth lines 10–11, weakly expressed.

Rostrum (Fig. 8E) a shorter isosceles triangle than in males, with basal width just greater than length. Apex rounded. First and second antennae as in male, but some of syntypes with one fewer lobe on first antennae.

Remainder of animal similar to male, except for tendency to have more spines (up to 10) on cercopods, with many of these spines mixed with last few setae.

Eggs variable (Figs. 5G,H). Most populations with eggs shaped like subconical cylinders (i.e. cupcake- or muffin-shaped) about 170 μm in diameter and height (range 168–174 μm, n = 6). Sloping sides with 16–20 parallel grooves, with narrow ridge within each groove, and low, wide ridges between, all generally sloping at about 30° from vertical axis of egg. Outer cortex with more included bubbles than in other species of *Limnadopsis*. Base generally with 2–4 parallel grooves on overall flat surface, but sometimes grooves crescent-shaped and not parallel. Dome of egg with many (4–8) grooves in parallel and grouped; highest point often off centre of vertical axis of egg. Occasionally (as in specimens from Fat Hen Lake), ridges between grooves possessing many included bubbles and dome lacking, thus egg is more cylindrical, and number of grooves on sides reduced to 10–12.

Variability. *Limnadopsis parvispinus* is a particularly variable species (cf. Figs. 8, 9). The carapace shape is reasonably standard, except for the difference in shape between males and females, but the number of growth lines in apparently mature specimens and their expression is quite variable. Generally there are about 12–15 growth lines, which are scarcely visible except near the dorsal margin. Populations with 10–12 lines occur in the Paroo, and there are 15–18 readily visible lines in individuals from Bollon. Henry (1924) gave the range as 12–14 lines, and all "well marked." Individual specimens are generally transparent and yellowish green (Henry, 1924), although those from Bollon are brown, especially near the dorsal margin.

While there is a consistent distinct difference in rostrum shape between males and females, in both sexes it is variable. In males, it may be rectangular or pointed, longer (length 2 twice depth) or shorter (length = depth), and the apex is sometimes curved ventrally. In females, it is always short and shaped like an isosceles triangle, but the height of the triangle is variable. The naupliar eye is always positioned near the base of the rostrum, but its orientation is variable, two common positions being aligned with the axis of the rostrum or with the base at a 45–60° angle to the rostrum axis. The population from Buster's Black Box Swamp, Queensland, had intersex "males" with a short rostrum and small claspers and no ordinary males.

The length of the first antenna is generally subequal to that of the peduncle of the second antenna, but in males it is slightly longer and has more lobes than in females. In males the lobes number 7–10, typically about 9, while in females the range is 7–9, with a mean of about 8. The peduncle of the second antenna typically has 12 apparent segments, while the number of flagellomeres varies from 14–21, often about 18.

Trunk segments generally number 25, but occasional specimens have 26. Posterodorsal thoracic armature in both sexes involves about the 6–7 most posterior segments each with 1–3 dorsal spines on a small protuberance, preceded by 6–7 segments with long hair-setae on similar protuberances, these decreasing in number and size anteriorly from many long setae per segment to 1–2 short setae per segment. The claspers are of standard structure for *Limnadopsis*, with the only variability noted in the spines tipping the movable finger; they are relatively small (cf. the spine in *L. tatei*) and number 1–3.

On the telson the most anterior dorsal spine in each row ranges from 1.25 times the size of the next few spines (in the syntypes) to otherwise about 1.5 times the size of the next few spines (in most specimens). Telsonic spines vary between 16 and 22 in number and are usually subequal in size and spacing, but uncommonly may be variable in both features. Almost always a few are placed on the ascending limb of the large, posterior, fixed telsonic claw. Although the caudal claws are generally long and thin (8–10 times longer than wide) with a long, straight, proximal section bearing the setae and spines, other proportions occur. The setae on the basal half of the caudal claws vary between 8 and 15 in number and generally are relatively short, particularly the last few, which often overlap with dorsal spines, situated at half to two-thirds the length of the caudal claws. These spines number 4–10 (often c. 6), with the most posterior the thickest, but not necessarily the longest. There are always many fine denticles on the dorsal surface of the curved, tapering apical part of the claw.

Limnadopsis minuta n.sp.

Figs. 2D, 5M, 10

Types. HOLOTYPE ♂ MAGNT Cr15704; allotype ♀ MAGNT Cr15705. PARATYPES 7♂, 10♀ MAGNT Cr15706 and 2♂, 2♀, AM P76809. All types: Northern Territory, E of Kununurra (WA), Keep River National Park, c. 15°57'S and 129°03'E, 8.ii.1986, M.J. Tyler, M. Davies & G. Watson.

Distribution. Known only from the type locality in the far west of the Northern Territory near the border with Western Australia.

Etymology. This species is named for its small size. At just less than 10 mm, and about the size of a typical species of *Limnadia*, it is the smallest known species of *Limnadopsis*, a genus known for its relatively large size among spinicaudatans.

Male. Carapace (Fig. 10A) 8.8 mm by 4.6 mm, L:D ratio of 1.9. Dorsal margin slightly convex and smooth, with only very minor carinae at posterior of the growth line and dorsal margin junctions. Carapace half-oval shaped with both ventral corners well rounded. Dorsoanterior angle and dorsoposterior angle both about 110° and carapace slightly expanded dorsoposteriorly. Umbo present but inconspicuous. Eighteen well expressed growth lines. Carapace surface minutely granular and uniformly brown in preserved specimens.

Head (Fig. 10B) with pyriform frontal organ behind eye mound and subequal to latter in height. Anterior surface of head and rostrum meeting at sharp angle, c. 110°. Rostrum about as long as frontal surface of head, slightly downturned at apex and containing triangular naupliar eye lying in a similar axis. First antenna a little longer than peduncle of second antenna with 8 lobules. Second antenna with peduncle of 12 apparent segments, many with numerous spines dorsally, and with two flagella of 18–20 flagellomeres. Most flagellomeres, particularly those in middle region of each flagellum (Fig. 10E), with c. 4 spines on anterior margin, usually with 2 (rarely 3) crowded apically and with the proximal surface bare.

Trunk segments 24, each bearing a pair of thoracopods, these decreasing in size posteriorly and the anterior two pairs modified as claspers. Posterior dorsal armature of 3–5 spines on small protuberances on about last 6 segments, many long setae on the 5 or so segments preceding these and a few setae on the next 4 or so more anterior segments. Claspers (Fig. 10D) of normal structure for *Limnadopsis*, with one spine apically on movable finger and asymmetrical protrusion near the base of anterior edge of hand.

Telson (Fig. 10C) with two rows of 17 dorsal spines, all sharp and varying a little in size. First spine about 1.5 times larger than the next few spines. Dorsal surface between lateral spinous rows with anterior hump on which telsonic setae are inserted, followed posteriorly by marked depression as surface generally evenly slopes to caudal claw articulations. Caudal claw about 8 times longer than wide, with long, almost straight, basal section of even width and much shorter, curved, apical part narrowing tosharp apex. Caudal claw basally with about 12–15 setae mediodorsally, most a little longer than its width, followed by 3–5 short spines inserted almost dorsally, posteriormost of these being by far (3×) the largest. Curved tapering apical part bearing many short denticles dorsally. Ventroposterior corner of telson with a spinous projection.

Female. Very similar to male. Carapace slightly larger, 9.2 mm by 5.1 mm, L:D ratio of 1.86, dorsal margin slightly curved. Head (Fig. 10F) with typical short rostrum of female *Limnadopsis*. First antenna with 6 lobules. Telson (Fig. 10G) as in male and both the features peculiar to this species: depression in the dorsal surface posterior to telsonic filament mound, and spiniform projection at ventroposterior corner.

Eggs (Fig. 45K) rounded polyhedral, about 160 µm in diameter (range 153–168 µm; n = 5). Each surface of polyhedron consisting of 1–3 oval grooves, each groove containing low longitudinal ridge internally and surrounded by high,

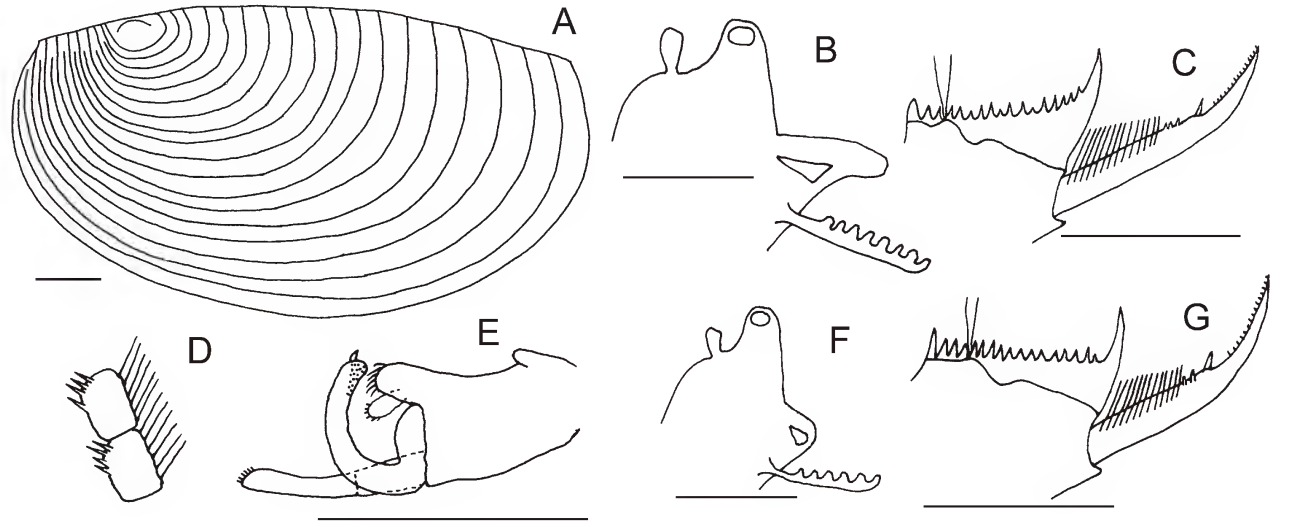

Fig. 10. *Limnadopsis minuta* n.sp., Keep River National Park, NT. Male: (*A*) carapace; (*B*) head; (*C*) telson; (*D*) a middle flagellomere of second antenna; (*E*) clasper. Female: (*F*) head; (*G*) telson. For clarity some growth lines of the carapace are incompletely shown anterior to umbo. Scale bars 1 mm.

rounded ridge, these meeting end-to-end in rounded protrusions. Either series of such protrusions or ridges forming edges of each polygon.

Comments. Other specimens in the single collection available show little variation from the type material. No other species of *Limnadiopsis* is so small yet has 18–19 growth lines, nor such a high L:D ratio, only 24 trunk segments, a spinous projection on the ventroposterior corner of the telson, a depression in the dorsal surface of the telson, and the unique egg characteristics. Overall, *L. minuta* is reminiscent of *L. tatei*, but it lacks the dorsal carinae of the carapace of *L. tatei* (although sometimes these are absent in *L. tatei*, too), the carapace shape is similar in males and females in *L. minuta*, its telsonic spines are more numerous and less variable in size and position than those of *L. tatei*, and there are fewer spines on the caudal claw in *L. tatei*. It is perhaps tempting to consider *L. minuta* as comprising juveniles of *L. multilineata* n.sp. (see below), especially given the superficially similar telsons and the large number of growth lines, but this is not possible in light of the markedly convex dorsal margin of the carapace in females of *L. multilineata*; the presence of a conspicuous ventroposterior expansion of the carapace and lack of a ventroposterior spinous outgrowth of the telson in that species; different spination of the antennal rami; and the completely different egg structure.

Limnadopsis multilineata n.sp.

Figs. 2E, 5C, 11

Types. Holotype ♂WAM C39334; allotype ♀WAM C39335, paratypes WAM C38102. Type locality: Western Australia, Kimberley, Mitchell Falls, rock pools at the top. 14°49'S 125°42'E, 14.i.1973, Smith-Johnstone.

Other material. **Western Australia**: via Broome, Lake Campion, 17°50'S 122°45'E, 28.iii.1996, C. Brockway, WAM C38103.

Distribution. Kimberley and adjacent area of northwestern Western Australia.

Etymology. The specific name refers to the large number of growth lines in this species.

Male. Carapace of mature individuals (Fig. 11A) about 10–12 mm long and 6–8 mm high, L:D ratio c. 1.5–1.6. Dorsal margin almost smooth and nearly straight, anterior angle distinct, about 100°, and dorsoposterior margin slightly depressed and ending in rounded protrusion. Umbo distinct, triangular in shape, but not protruding above the dorsal margin. Anterior edge of carapace evenly curved, ventral edge almost straight, and posterior edge protruding and rounded so that it is convex posteroventrally and concave dorsoposteriorly. About 20 distinct growth lines with a further 10–12 closely spaced lines on outer 10–15% of carapace. Carapace brown and surface apparently granular, but "grains" actually comprising numerous dendritic pigment cells.

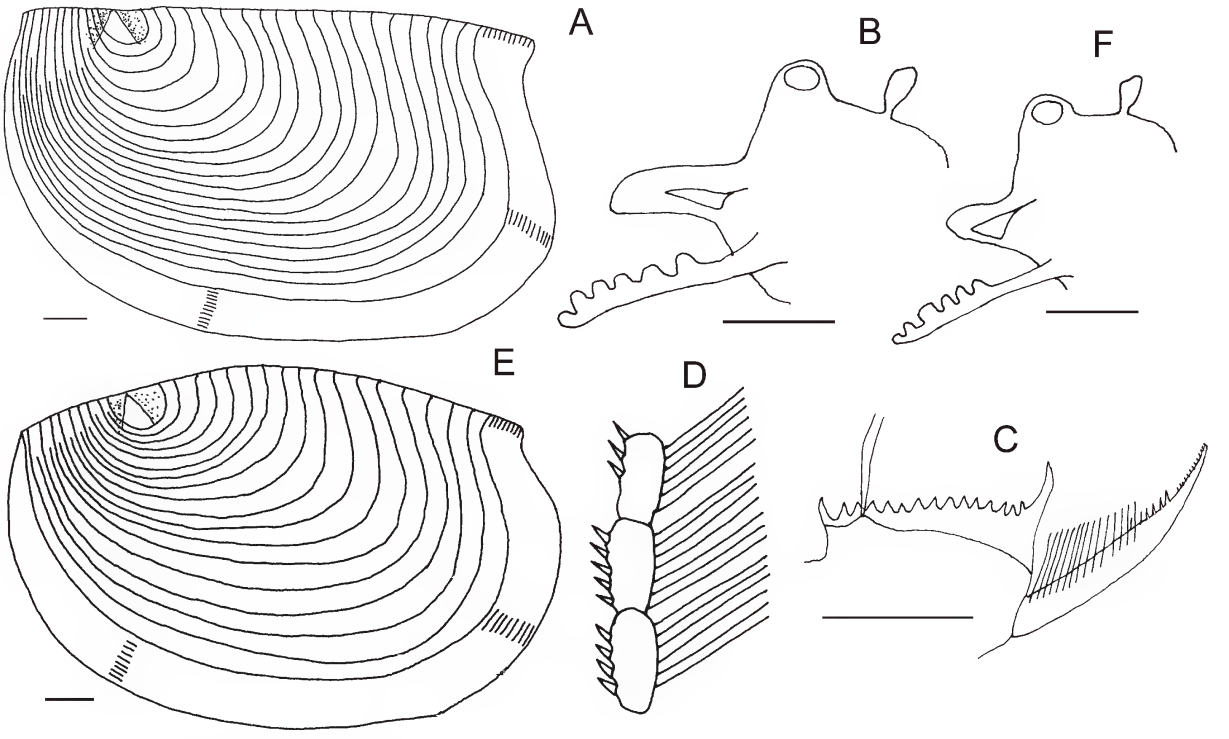

Fig. 11. *Limnadopsis multilineata* n.sp., Mitchell Falls, Kimberley, WA. Male: (*A*) carapace; (*B*) head; (*C*) telson; (*D*) a middle flagellomere of second antenna. Female: (*E*) carapace; (*F*) head. For clarity, some growth lines are incompletely shown anterior to umbo and marginally. Scale bars 1 mm.

Head (Fig. 11B) with pyriform frontal organ placed posteriorly and protruding a little farther than eye mound. Anteriorside of eye mound and rostrum meeting at about 120°, junction angular. Rostrum protruding with almost parallel dorsal and ventral edges and downward curving apex. Naupliar eye triangular with largest surface ventral. First antenna subequal in length to peduncle of second antenna and having about six lobules. Second antenna with peduncle of 12 apparent segments and two flagella of about 20 flagellomeres each. Most second antennal segments, particularly in the region of each flagellum, bearing 3–5 spines anteriorly (Fig. 11D).

Trunk segments usually 26, each bearing pair of thoracopods, these decreasing in size posteriorly and with anterior two pairs modified as claspers. Posterodorsally each segment with large, rounded protuberance, this bearing 5–7 large spines on last five segments, many setae on next 5 segments anterior to these, and 1–3 setae on most other segments. Claspers of normal structure for *Limnadopsis*, with single spine apically on movable finger.

Telson (Fig. 11C) with about 15 spines in each dorsal row, largely saw-tooth in appearance, i.e. shaped like isosceles triangles, but first two narrower, first a little longer than second. Two telsonic setae inserted on protuberance situated about one fifth of way along dorsal side of telson. Caudal claws about 9–10 times longer than wide, fairly evenly curved ventrally and bearing about 14–18 setae mediodorsally, followed by about 6 short spines dorsally and numerous denticles on the markedly curved apical quarter of claw. First one or two spines sometimes arising between last few setae.

Female. Largely similar to male, except in carapace shape (Fig. 11E), rostrum shape (Fig. 11F), and lack of claspers. Dorsal margin of carapace evenly arched, almost smooth. Dorsoanterior angle distinct, about 110°, dorsoposterior angle as in male, but not so marked. Umbo as in male. Anteroventral area of carapace more convex than in male, while posteroventral area also expanded as in male but more posteriorly than ventrally, thus giving an appearance of greater posterior expansion than in male. Growth lines as in male.

Head (Fig. 11F) with proportionally smaller eye than in male, and thus with pyriform frontal organ protruding more dorsally than in male. Rostrum short, almost in form of isosceles triangle, with rounded apex. Naupliar eye triangular and occupying about half of rostrum.

Eggs (Fig. 5C) most unusually shaped and structured; somewhat bell-shaped, about 240 µm high and about 220 µm in diameter (range 236–242 µm high, 218–223 in diameter, n = 5), with about 7 (6 around the circumference and one ventrally) large grooves separated by unevenly developed sharp ridges, some of latter meeting at top in distinct point. Each groove containing smooth, weakly developed subsidiary ridge.

Variability. Specimens from Broome are a little different from the type lot. The carapace tends to be slightly larger at 11–12 mm by 7–8 mm, but the unusual shape is the same as in males and females from Kimberley. The dorsal margin is more irregular than in the Kimberley specimens, but still basically smooth. There are only 25 growth lines, with nearly 20 of these distinct and well spaced and 4–6 situated marginally and closely spaced; therefore they do at least feature the same unusual arrangement of many well-spaced lines and a few tightly-spaced lines. The first antennae have 7 lobules and the second antenna 18 flagellomeres, both figures being slightly different from the type lot. The telson also armed differently: 16–18 dorsal spines with the first one 1.5 times larger than the rest, and caudal claw with about 15 long setae and 4–5 spines two-thirds of the way along its length.

Comments. This species is distinctive by reason of its carapace shape and its possession of numerous growth lines arranged in two groups about 20 normally spaced lines and 4–10 marginal lines spaced very closely together. It has many (ca 5–6) spines midlength on the cercopods, as do *L. parvispinus, L. occidentalis* and *L. minuta*, but is easily distinguished from these species by its unique carapace as mentioned above, and in contrast to *L. parvispinus* and *L. occidentalis*, by the well expressed growth lines (as opposed to faint lines), and 1–2 fewer spines on the middle flagellomeres. Features distinguishing it from *L. minuta* are noted above.

Limnadopsis occidentalis n.sp.

Figs. 2F, 5J, 12

Types. Holotype ♂ WAM C39336, allotype ♀ WAM C39337, paratypes, 2♂, 2♀, WAM C39338. Type locality: Western Australia, N of Carnarvon, Boolathana Station, unnamed claypan, 24°38'34"S 113°59'35"E, 15.iii.1995, S.A. Halse.

Other material: **Western Australia**: 2♂, 8♀, 58.6 km south of Roebourne, small pools adjacent to creek, 20°48'S 117° 6'E, 25.vi.1964, C. Pugh, AM P55651; 1♂, 131 mile post, road to Port Headland via Woodstock, waterhole, 21°12'S 118°48'E, 26.vi.1964, C. Pugh, AM P55650; 6♂, 2♀, E of Kalbarri, Coolcalalaya Station, unnamed clay pan, 27°31'29"S 115°05'14"E, S.A. Halse, 15.iii.1995, WAM C39339; c. 40 km south of Mullewa, Tardan, Christian Brothers College, dam, 28°43'S 115°49'E, 25.vii.1999, J. McRae & A. Pinder, DEC, Woodvale, SPS185; 1♀, via Laverton, 20 km west near highway, samphire swamp, 28°36'S 122°13'E, 17.ii.2003, B. Datson, WAM C39340.

Habitat and distribution. *Limnadopsis occidentalis* lives in a variety of temporary fresh waters, including claypans and floodplain pools, all in northwestern Western Australia.

Etymology. The species name is derived from the Latin *occidens* referring to the direction of the setting sun, and hence "west" an appropriate epithet for a species found in the west of Australia as opposed to its closely related species *L. parvispinus*, which is found in eastern Australia.

Male. Carapace (Fig. 12A) oval, 11 mm by 6 mm, L:D ratio = 1.8. Dorsal margin weakly convex with highest point at about one-third length, slight depression anterior to umbo and distinct dorsoposterior angle. Dorsal margin almost smooth, but with slight serrations at many growth lines, mainly posteriorly. Growth lines 11, weakly expressed. Carapace weakly granulated within, but presenting a smooth yellow-buff surface in preserved condition.

Head (Fig. 12B) with pyriform organ posterior to eye mound and about as high as latter. Anterior sides of eye mound and rostrum both straight and meeting at a distinct angle of about 110°. Rostrum elongated triangular, about as long as anterior surface of head, apex rounded and slightly flexed downward. Naupliar eye triangular, its axis aligned similarly to that of rostrum. Length of first antenna subequal to that of peduncle of second antenna, and former bearing 7 lobules. Second antenna with 12 apparent peduncular segments and 15–16 flagellomeres on flagella, most middle segments with 5–7 spines, 2 of which sometimes grouped apically.

Trunk segments 25 in number, each bearing pair of thoracopods, these decreasing in size posteriorly, and anterior two pairs modified as claspers. Posterior dorsal armature comprising 1–3 spines on small protuberances on each of last 7 segments, and a few setae on preceding 6 segments. Claspers of normal structure for *Limnadopsis*, with one spine apically on the movable finger, and prominent, asymmetrical protrusion midway along anterior edge of hand.

Telson (Fig. 12C) with two rows of 13 dorsal spines each. Most anterior spine about 1.5 times the size of next spine, most posterior spines smaller and sharper than anterior spines, and spines in middle of row more widely spaced than anterior or posterior spines. Two telsonic setae inserted on protuberance situated about one quarter of way along dorsal side of telson. Caudal claws about 8 times longer than wide, with long, almost straight basal section of even width and much shorter, curved apical part tapering to a sharp apex. Basally, cercopods bearing about 12 setae mediodorsally, most of them being a little longer than width of claw, followed by 3 short spines inserted almost dorsally, the posteriormost the largest. Curved, tapered apical part of cercopods bearing many short denticles dorsally.

Female. Carapace (Fig. 12D) oval, 11 mm by 7 mm, L:D ratio 1.57. Dorsal margin more convex than in male and also with distinct depression in umbo area. Dorsal margin largely smooth, but minor serrations present posteriorly at junctions of growth lines. Growth lines 9, weakly expressed.

Head (Fig. 12E) typical for females of *Limnadopsis*, with short triangular rostrum. Six lobules on first antenna. Second antenna as in male.

Telson (Fig. 12F) similar to that of male, but with 15 telsonic spines in each row, and six spines on caudal claws.

Eggs (Fig. 5J) round, about 175 μm in diameter (range 170–178 μm; n = 5) with short deep grooves, aligned at most in pairs, otherwise set at various angles to one another. Intergroove areas smooth and internally frothy.

Variability. Considerable variability was noted in representatives of the six populations studied. Growth lines vary from 9 to12, but they are invariably weakly expressed and meet the dorsal margin in at most weak dorsal serrations posteriorly. First antennal lobules vary from 6 to 9, with males of a given population generally having one more than females. On the telson, the dorsal spines vary from 12 to16 per row, with a mean of 13; and the spines on the caudal claws range from 2 to 6, usually about 4.

Comments. This species is similar to *L. parvispinus*. Despite wide variation in many features of both species, there are many differences between the two, including: (*a*) fewer telsonic spines in *L. occidentalis* (about 13–15 per row compared to about 18–22); (*b*) A slight anterior depression in the dorsal carapace margin of *L. occidentalis* while in *L. parvispinus* the margin is straight or slightly convex; (*c*) the differently shaped eggs, round in *L. occidentalis* and with the grooves ungrouped or at most in pairs, compared to cy-

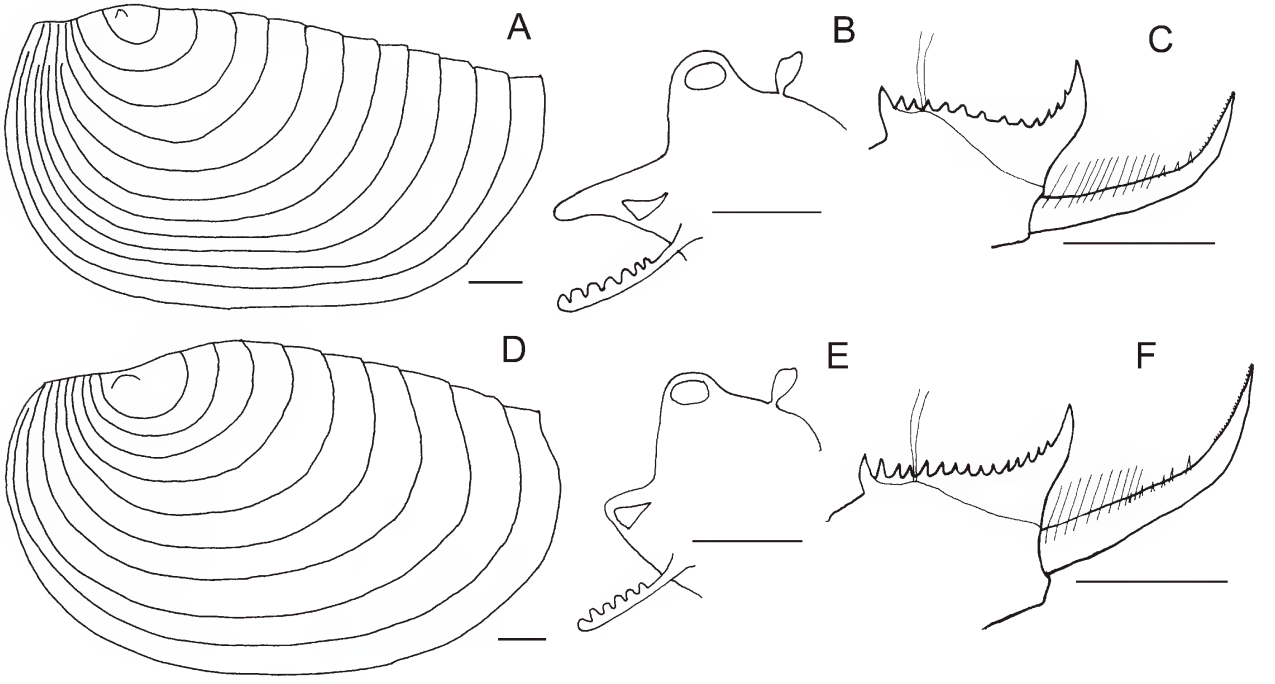

Fig. 12. *Limnadopsis occidentalis* n.sp., Boolathana Station, via Carnarvon, WA. Male: (*A*) carapace; (*B*) head; (*C*) telson. Female: (*D*) carapace; (*E*) head; (*F*) telson. For clarity some growth lines of the carapace are incompletely shown anterior to umbo. Scale bars 1 mm.

lindrical to muffin-shaped in *L. parvispinus* with multiple parallel grooves in the outer cortex; (*d*) most flagellomeres have six dorsal spines in *L. parvispinus*, but five in *L. occidentalis*; (*e*) fewer setae and fewer spines on the caudal claws in *L. occidentalis* (ca 12 setae in *L. occidentalis* and c. 15 in *L. parvispinus*; 2–6 spines in *L. occidentalis* and 4–9 spines in *L. parvispinus*); and (*f*) usually one fewer lobule in the first antenna in *L. occidentalis* (6–9, verses 7–10 in *L. parvispinus*).

Limnadopsis paradoxa n.sp.

Figs. 2G, 4D, 5K,L, 13

Types. Holotype ♂ WAM C39341, allotype ♀ WAM C39342, paratypes 2♂, 2♀, WAM C39343, 3♂, 2♀, AM P76808. Type locality: Western Australia, E of Grass Patch, Sieda Farm, Fitzgerald Paddock 81, temporary pool, 33°13'S 121°47'E, 2.ii.2007, B.V. Timms.

Other material. **Western Australia**: 4♂, S of Newdegate, Lake Bryde, 33°21'S 118°49'E, 21.iii.2006, D. Cale, WAM C39344; c. 20 individuals, S of Newdegate, Lake Bryde East, 33°22'S 118°54'E, 21.iii.2006, D. Cale, WAM C39345; c. 20 individuals, SE of Salmon Gums, along Guest Rd, temporary pool in paddock, 33°06'S 121°46'E, 25.i.2007, B.V. Timms, WAM C39346; > 50 individuals, E of Grass Patch, Sieda Farm, Fitzgerald Paddock 81, temporary pool, 33°13'S 121°47'E, 2.ii.2007, B.V. Timms, WAM C39347; >50 individuals, SE of Scaddan, Truslove Nature Reserve, a paperbark swamp, 33°20'50"S 121°46'5"E, 27.i.2007, B.V. Timms, WAM C39348. **South Australia**: 1♂, N of Woomera, Olympic Dam, 30°28'S 136°44'E, 12.ii.1981, M.J. Tyler, SAM C6351. **New South Wales**: 1♂, near Wilcannia, roadside ditch 19.5 km east of town, 31°41'S 143°427'E, 14.i.2007, B.V. Timms.

Habitat and distribution. *Limnadopsis paradoxa* lives in freshwater intermittent ponds and lakes, that are somewhat turbid or humic. More is known about the habitat of this new species than the others, because the author is personally familiar with the area. The ponds and lakes fill every few years and may take two or more years to dry (e.g., Lake Bryde, Cale *et al*., 2004) or dry within months (e.g., pools on Sieda Farm, A. Longbottom, pers. comm.). In all sites it was found only in the early period of inundation. It is known mainly from the southeastern wheatbelt of Western Australia, specifically south of Newdegate and north of Esperance. Two outlier populations were found much further east, in central South Australia and in southwestern NSW.

In Lake Bryde, it was collected in March, 2006, six weeks after a major filling, and at the time the lake was fresh (EC 549 µS/cm), alkaline (pH 7.8), warm (21.8°C), well oxygenated (88% saturation), and only slightly coloured (D. Cale, pers. comm.) This lake fills to overflowing only occasionally (every few years in the 1990s to 2000s, S. Halse, pers. comm.); normally the episodic fillings result in a shallow, fresh to slightly saline lake that takes 12–24 months to dry. At such times it holds the clam shrimps *Caenestheria* sp. and *Caenestheriella* sp., but apparently not *Limnadopsis paradoxa* (Cale *et al*., 2004).

In seven sites at Grass Patch it appeared as adults within three weeks of filling in late January, 2007. These ponds are c. 20–50 m in diameter, saucer-shaped and up to 2 m deep. They were once *Melaleuca* swamps, but many are now usually farmed for cereals. They fill partially, or deeply as

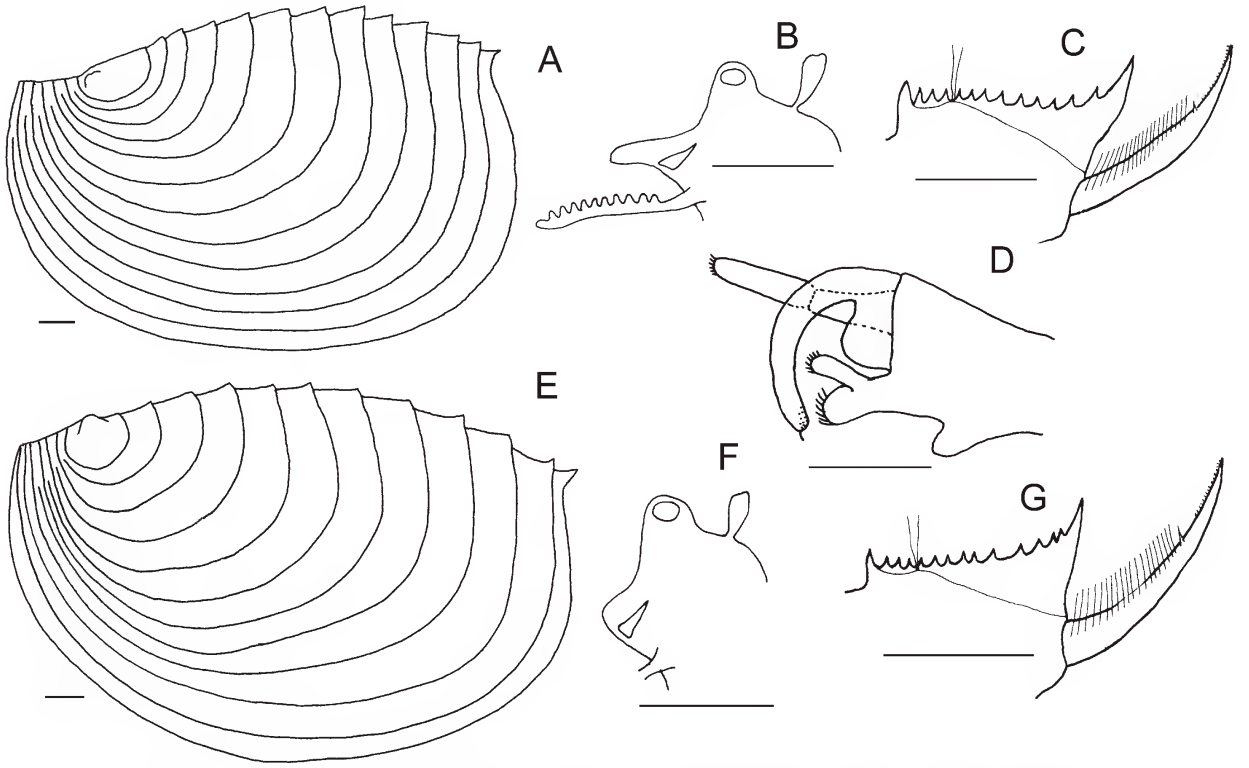

Fig. 13. *Limnadopsis paradoxa* n.sp., Sieda Farm, Grass Patch, WA. Male: (*A*) carapace; (*B*) head; (*C*) telson; (*D*) second clasper. Female: (*E*) carapace; (*F*) head; (*G*) telson. For clarity some growth lines of the carapace are incompletely shown anterior to umbo. Scale bars 1 mm.

in 2007, in wet summers, generally about once every 5–10 years (A. Longbottom, pers. comm.). Their water is humic (40–150 NTU), fresh (conductivity 260–440 µS/cm), warm (21–28°C), and acid to slightly alkaline (pH 5.8–7.4). By early March 2007, all of the ponds sampled had declining senescent populations, or none at all.

Etymology. The species name derives from the paradox presented upon first examination: it has a carapace resembling *L. birchii* and a body-form superficially resembling *L. tatei*, but it differs from these two species on detailed examination.

Male. Carapace (Fig. 13A) 14.6 mm long by 9.9 mm deep, L:D ratio c. 1.5. Dorsal margin doubly curved so lowest point at anterior umbo area and highest point about two-thirds of way along the hinge line. Hinge line uneven with growth lines protruding as small carinae, these generally more prominent posteriorly. Umbo humped dorsoanteriorly. Growth lines 12, expressed, crowded anteriorly, but more spaced spaced posteriorly. Carapace coloured dark humic brown.

Head (Fig. 13B) with a pear-shaped pyriform frontal organ posteriorly, preceded by rounded prominence containing eye, then by large rostrum at right angles to head. Length of rostrum similar to length of anterior surface of head and about twice its own basal width. Rostrum curved downwards apically and containing triangular naupliar eye dipping at angle to rostrum axis and occupying much of its basal area.

First antenna with 11 subequal lobes, slightly longer than peduncle of second antenna. Two flagella each bearing 15–18 beaded flagellomeres, each of latter with up to 6–7 spines evenly spaced along dorsal surface.

Trunk segments 26. Dorsally, posteriormost segment with spineless protuberance, preceding 7–8 segments each with 3–5 spines on protuberance, then further anteriorly another 7 segments with 5–9 long setae each. Hand of claspers with blunt narrow outgrowth near inner basal corner. Third thoracopod (Fig. 4D) similar in structure to that of *L. birchii*. Proportions of endites, endopod, exopod and epipodite slightly different, and significantly palp of fifth endite slightly shorter than fifth endite and epipodite proportionally smaller. Other thoracopods of same basic structure, but without palp and with larger epipodite.

Telson (Fig. 13C) with two rows of 13 to 14 strong, subequal spines, although the first spine slightly larger than next few spines and curving slightly posteriorly, middle spines slightly smaller and posterior spines more widely spaced, and sharper last spine near apex of claw. Two telsonic setae inserted on protuberance about one quarter of way along dorsal side of telson. Caudal claws well developed, at least twice as large as telsonic claws, curved concavely dorsally, with basal two-thirds bearing about 20 setae mesodorsally and terminating in a spine. Apical third of claw with many fine denticles dorsally.

Female. Carapace (Fig. 13E) 13.5 mm by 9.7 mm. Similar to that of male, but anterior concavity less pronounced and highest point of carapace at about midlength. Carinae of growthlines prominent, but blunt compared with those of male.

Head (Fig. 13F) similar to that of male, but rostrum short, about as long as deep, and blunt. Naupliar eye of about same size and position as in male, thus occupying much of rostrum. First antenna shorter than in male, with about 8 lobes. Second antenna as in male.

Number of body segments, and details of telson (Fig. 13G) similar to those in male.

Eggs (Figs. 4L,M) top-shaped, with prominences dorsal and ventral and about 5 prominences around equator. Typically about 16 grooves between equator and dorsal and ventral prominences, and about 3–4 grooves between each equatorial prominence. Ridges between grooves may be straightish or Y-shaped, the latter generally in the fields between equatorial and dorsal or ventral grooves. Sometimes only 4 equatorial prominences present and grooves somewhat randomly distributed. Maximum dimensions about 250 µm (range 241–254 µm, n = 20).

Variability. The carapace size varies from c. 13 to16 mm, growth lines from 10 to 14, first antennal lobes 9 to 11, telsonic spines 15 to 18, and caudal claw setae from 16 to 21. There is no significant variation in the characteristic carapace shape, and all specimens have just one spine on the caudal claws.

Comments. *Limnadopsis paradoxa* resembles small specimens of *L. birchii*, on account of its size, general shape, development of the carinae, and perhaps colouration. However, the body inside bears absolutely no resemblance to that of *L. birchii*. For instance there are 26 body segments, not 32, and there are only c. 14 telsonic spines on a almost straight edge compared to c. 50 spines on a doubly curved edge. The new species is most like *L. tatei* but has more growth lines, more lobes on the first antenna, more telsonic spines and more setae on the caudal claws. Perhaps it could be regarded as a bigger form of *L. tatei*, but the shape of the carapace is distinctive, particularly the concave dorsal surface and the lateral development of the umbo. The smaller first:second telsonic spine size ratio in *L. paradoxa*, and more numerous caudal claw setae are also distinctive. *Limnadopsis pilbarensis* n.sp. (see below) differs by having a convex edge in the umbo area, much less pronounced development of the dorsal outgrowths of the growth lines, and fewer telsonic denticles and setae on the caudal claws.

The eggs of *L. paradoxa* and the three other above-mentioned species are distinctive among themselves. At 40× magnification, eggs of *L. birchii* and *L. tatei* are smoothly round with groups of parallel grooves, more of the latter in *L. birchii* than in *L. tatei*. Eggs of *L. paradoxa* and *L. pilbarensis* both have rough surfaces, but those of *L. pilbarensis* have many (> 20) spines and those of *L. paradoxa* have just a few (<8) rounded prominences. These distinctions are even more pronounced as observed by SEM (Fig. 4).

Limnadopsis pilbarensis n.sp.

Figs. 1, 2H, 5F, 14

Types. Holotype WAM C39349, allotype WAM C39350, paratypes 1♂, 1♀, WAM C39351. Type locality: Western Australia, Pilbara, N of Karratha, Burrup Peninsula, unnamed rockhole, 20°34'25"S 116°48'27"E, A Pinder & J. McRae, 20.viii.2005.

Other material. **Western Australia**: 8 individuals, Pilbara, Chichester Range, Beabea Creek, 21°36'S & 118°38'E, J. Wombey, 21.vi.1970, WAM C38103; 1 ♂, 3♀, via Paraburdoo, Ratty Spring on Pirraburdu Creek 7 km west of Paraburdoo, 23°15'S 117°28'E, 1.iv.1979, J.A. McNamara, WAM C39352; 6 individuals, Glen Ross Creek, Pilbara, WA, 24°10'44"S 118°01'48"E, site PSW085 of Department of Environment and Conservation, collected by A. Pinder & J. McRae, 9.ix.2005.

Etymology. This species gains its name from the district, the Pilbara, from which all the present material was collected. I also wish it to honour my great-uncle, Tom Starr, who spent much time "in the early days" exploring for gold in the Pilbara and made a significant discovery at Marble Bar in the 1930s.

Male. Carapace (Fig. 14A) 10 mm long by 6.5 mm deep, L:D ratio c. 1.5. Dorsal margin curved with highest point just posterior to larval valve growth line, i.e. about one-third of way from anterior end; curvature greater anteriorly than posteriorly to this high point. Growth lines 9–10, expressed, crowded anteriorly, spaced posteriorly. Posteriorly at hinge line, younger (i.e. outer) growth lines humped, each more so than previous line. Carapace with granular surface texture.

Head (Fig. 14B) posteriorly with pyriform frontal organ posteriorly, preceded by rounded prominence containing eye, a tiny protuberance below eye and a large rostrum at right angles to head. Rostrum somewhat longer than distance between eye and pyriform organ, curved downwards at its apex, and containing triangular naupliar eye dipping at angle to the rostrum axis and occupying much of its basal area. Rostrum length twice its own basal width.

First antenna with 9–10 fairly evenly-sized lobes; usually a spine present near base on same side as lobes. Second antenna with two flagella each of about 12–16 beaded flagellomeres, these of variable length but generally longer and bigger basally. Flagellomeres around midlength each with 7–9 setae on dorsal surface.

Trunk segments 25–26 in number. Dorsally, posteriormost segment with spineless protuberance, preceding 7–8 segments each with 3–5 spines on protuberance, then further anteriorly another 7–8 segments with long setae varying from many posteriorly to 1–2 on more anterior segments. Hand of claspers (Fig. 14D) with asymmetrical outgrowth near inner basal corner. Immovable finger with numerous spines apically, central ones short and stout, giving way to long, thin curved spines on inner edge. Palp of movable finger short with setae apically. Base of movable finger with evenly curved, slight protuberance opposite immovable finger, and evenly curved finger terminating in small spine. Palp of hand two-segmented, as long as hand in first clasper and about half as long again in second clasper; distal segment bearing many short setae apically, but no setae on junction of palp's two segments.

Telson (Fig. 14C) armed with two rows of about 11 strong, subequal spines, although anterior spine almost twice as

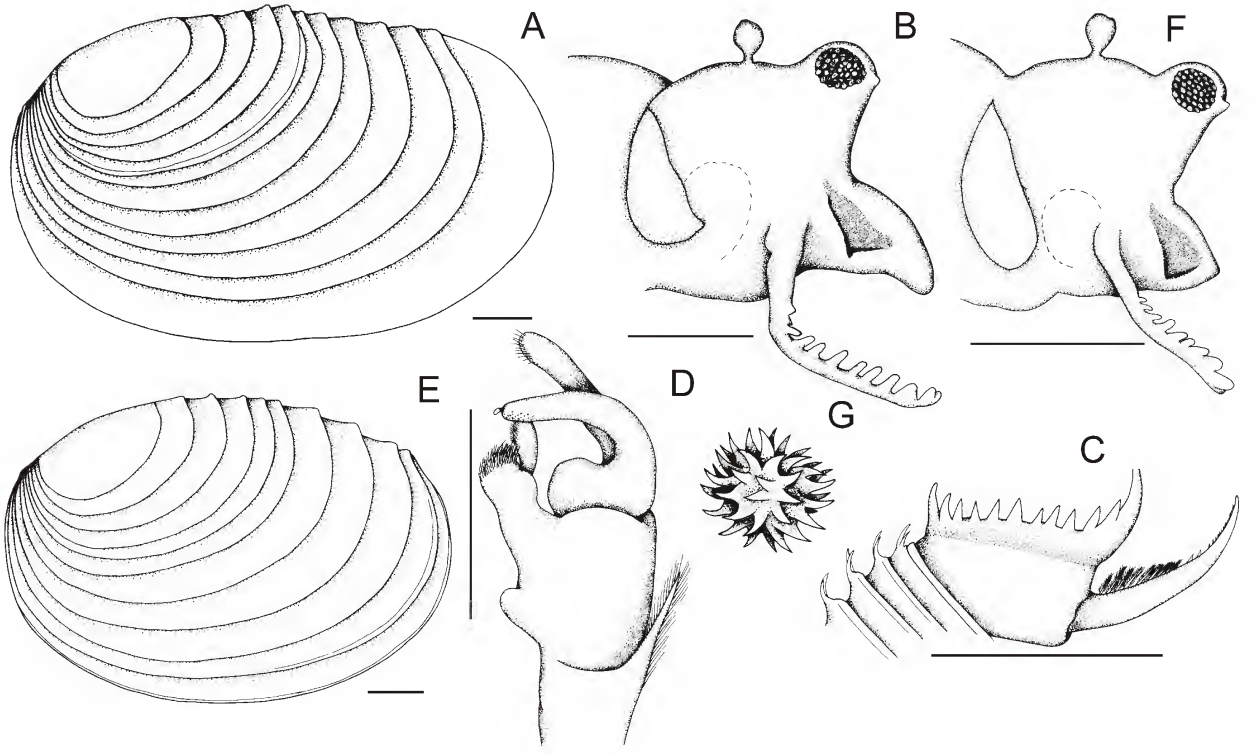

Fig. 14. *Limnadopsis pilbarensis* n.sp., unnamed rockhole, Burrup Peninsula, Pilbara, WA. Male: (*A*) carapace; (*B*) head; (*C*) telson; (*D*) first clasper. Female: (*E*) carapace; (*F*) head; (*G*) egg. Scale bars 1 mm. Drawn by Jane McRae.

large as the others and curving slightly posteriorly; last 2–3 spines on curved, telsonic claw; this claw curved anteriorly and more than twice as long as basal width.Two telsonic setae inserted on protuberance about one quarter the way along dorsal surface of telson. Caudal claws well developed, at least twice as large as telsonic claw and curved concavely forward. Basal half thick, almost straight, and bearing about 10 shortish setae mesodorsally. Two short spines located about two thirds of way along each caudal claw on dorsal surface, followed by row of many denticles situated dorsally on pointed apex of caudal claw.

Female. Carapace (Fig. 14E) 10 mm by 6 mm. Similar to that of male, but hinge line slightly more curved.

Head (Fig. 14F) similar to that of male, but rostrum short, about as long as deep, and blunt. Naupliar eye of about same size and position as in male, occupying much of rostrum. First antennae shorter than in male, with about 6 unequal lobes and generally no basal spine. Second antenna as in male, but generally with only about 12 beaded flagellomeres, rarely a few more to a miximum of 15.

Number of body segments, posterodorsal armature, and telson similar to those in male.

Eggs (Figs. 5F, 14G) subspherical, about 250 μm in diameter (range 247–252 μm, n = 5). Surface very irregular with deep conical pits (n = c. 20) bordered by thin, expressed ridges. Where three ridges meet, surface is further expressed as spines visible in light microscopy.

Comments. *Limnadopsis pilbarensis* is most similar to *L. tatei*. Many features of *L. pilbarensis* lie within the range of variability seen in *L. tatei*, including valve size, number of growth lines, rostrum shape and relative size, first antenna lobe number, number of flagellomeres of second antenna, number of body segments, gross structure of claspers, and many features of the telson. However *L. pilbarensis* is distinctive in its carapace structure: (*a*) it lacks dorsal carinae, although the dorsal margin is humped where the growth lines meet it, (*b*) in males the dorsal margin is always markedly curved whereas in *L. tatei* it is weakly curved or straight, (*c*) carapace tends to be ballooned in *L. pilbarensis* but *flattish* in *L. tatei*, and (*d*) the growth lines in *L. pilbarensis* are particularly clearly visible, being well expressed and generally coloured brown to black on a yellowish carapace background. The dorsal telsonic spines are also different in the two species: although there are similar in number, those in *L pilbarensis* are subequal and fairly evenly spaced, while in *L. tatei* they vary much in size and spacing. Also, the anteriormost spine is about 1.5 times the size of the others in *L. pilbarensis* and 2 times or greater in *L. tatei*.

Limandopsis pilbarensis cannot be confused with the other species of *Limnadopsis* besides *L. tatei*. It is easily distinguished from *L. birchii* by the much smaller size, fewer body segments, significantly fewer telsonic spines and lack of carinae on the carapace. Though similarly lacking carapace carinae, *L. parvispinus* is a little larger (> 12 mm) and significantly has more (>13) telsonic spines and more (>11) growth lines than *L. pilbarensis*. Furthermore, the carapace in *L. parvispinus* is expanded posteriorly beyond the dorsoposterior corner, but not in *L. pilbarensis*. Among limnadiids and possibly most Australian branchiopods, the eggs are particularly distinctive with their conical pits and spinous outgrowths.

Limnadopsis brunneus Spencer & Hall, 1896, nomen dubium

Limnadopsis brunneus Spencer & Hall, 1896: 243, pl. 23, figs. 28–29; Sayce, 1903: 250; Wolf, 1911: 254 (list); Dakin, 1914: 295 (list); Henry, 1924: 122 (list), 132 (key); Brtek, 1997: 58 (list).

Limnadiopsis brunneus.—Daday, 1925: 183–184, fig. 124 (misspelling of genus name); Schneider & Sissom, 1982: 72–73 (misspelling of genus name).

Types. None designated, though the four dried specimens used to erect this species (Spencer & Hall 1896) would be syntypes, but they are missing. Type locality: Knuckeys Lagoon, Darwin, NT.

Comments. Spencer & Hall (1896) erected this species, noting only that the carapace carinae were not as strongly developed as in *L. tatei*, and that there were 30–34 growth lines. Their diagram shows only 20 growth lines, and virtually no dorsal carinae. Immediately this presents a major problem, as the diagram and brief description do not match. No specimens are available in any Australian Museum, although Schneider & Sissom (1982) claimed to have found this species in the Kimberley. These specimens are now lost (S. Sissom, pers. comm.) and there is doubt over their identity based on their description of only 20 growth lines (see Richter & Timms, 2005). The author visited the type locality in the wet season (late February, 2007) and was unable to find any specimens, nor later raise any *Limnadopsis* from dried mud collected from the site. As a further complication, it is just possible the presently described *L. multilineata* is in fact *L. brunneus*, based on the written description of the latter. Similarly, and based only on Spencer & Hall's (1896) diagram, the present *L. minuta* could be in fact *L. brunneus*. Hence the animal remains an enigma and therefore is considered a nomen dubium.

Discussion

Variability. Spinicaudatans are notoriously variable in their morphological characteristics (D.C. Rogers, pers. comm.). Straškraba (1965a) noted that in the Limnadiidae, and specifically in *Limnadia lenticularis*, the carapace shape, number of growth lines, dorsal extension of the growth lines, and numbers of telsonic spines and setae and spines on the caudal claw are all variable in expression. Cycizids are even more variable in these and other characters (Straškraba, 1965b). The situation in *Limnadopsis* is no exception, with variation within and between populations noted particularly in the numbers of growth lines, telsonic spines, and spines of the cercopods, and to a lesser extent in carapace shape, and expression of dorsal carinae of the carapace. Adult size is also variable, but this is also influenced in spinicaudatans by nutrition during development (D.C. Rogers, pers. comm.). Although the dorsal trunk spination and setation has been described for each species, these features are also variable within species, probably at least partly associated with predation pressure (D.C. Rogers, pers. comm.). Some species are more variable than others, with *L. tatei* being the most variable, and *L. birchii* the least variable, of those for which numerous specimens have been examined.

Sex is easily determined by examining the rostrum (long in males and short in females) and by the presence of claspers in males. Carapace shape can also be different, especially in *L. tatei* and *L. multilineata*, and to a much lesser extent in *L. parvispinus, L. paradoxa*, and *L. pilbarensis*, with carapaces being more humped dorsally in females than in males of these species. An interesting intersex condition was observed in one population of *L. parvispinus*, in which males had a short rostrum and claspers smaller than usual. Of various intersex conditions known in limnadiids this is most unusual (Sassaman, 1995; S. Weeks pers. comm.).

Despite this variability, by reference to many characteristics, species can be delineated, despite overlap in some counts such as number of growth lines or telsonic spines. More disconcerting is the occasional finding of a specimen well outside the normal range in just one character when the remaining features all indicate a particular species. This is seen mainly in counts of telsonic spines, so that ranges given for some species, e.g., *L. tatei, L. parvispinus*, are much wider than normally seen in an attempt to encompass this variability. Perhaps such oddities are explained by development abnormalities. More easily explained are areas of the body so damaged during development that they assume a different shape or number of parts than usual. Body parts most easily damaged seem to be the male rostrum (e.g., Fig. 8B of *L. parvispinus*), carapace edge, and the caudal claws.

In diagnosing species, the most useful characters, because of their consistency between species, are shape of the carapace, particularly the convexity of the dorsal margin and posterior edge; the relative development of the dorsal carinae; the number of body segments; the number of spines on the caudal claws; and also the surface morphology of the eggs. Also useful in differentiating some species are, the number and relative size of the telsonic denticles, the curvature of the dorsal telsonic surface, the number and expression of the growth lines, the number of spines on the dorsal margin of the middle flagellomeres of the second antennae, and the number of caudal claw setae. There is little difference between species in the macroscopic structure of the claspers, although microscopic studies using SEM is proving fruitful in *Limnadopsis* (S. Richter, pers. comm.). From the study of the thoracopods of just four of the eight species, there seems to be only minor differences between species, although all are clearly different from those of other spinicaudatan genera. Thoracopods of *Limnadopsis* (Fig. 4) are characterized by a long fifth endite, that is of similar structure to the endopod, and by a one-segmented palp on just the third pair of thoracopods, and in males only. The structure of the head, second antenna and to a lesser extent the first antennae are conservative throughout the genus and of little use in delineating species.

Limnadiopsium. Novojilov (1958) split the genus *Limnadopsis* (misspelt as *Limnadiopsis*) into *Limnadiopsis* (sic) and *Limnadiopsium*. Novojilov placed *Limnadopsis tatei* into his *Limnadiopsium* and left *Limnadopsis birchii* (misspelt as *L. brichii*) in *Limnadopsis*. He was apparently unaware of *Limnadopsis parvispinus* and thought *L. brunneus* belonged to a third genus. Furthermore, he erected holotypes "on paper" for both species based on the material the original authors used in their descriptions (for *L. birchii*: "Holotype: spécimen décrit par Baird"; for *L. tatei*: "Holotype: spécimen décrit par Spencer et Hall 1896"—Novojilov, 1958:104–105) It seems from the text that Novojilov (1958) did not see the original descriptions as he quotes Daday de Deés, 1925, fig. 122 in the case of *L. birchii* and fig. 123 in the case of *L. tatei*. No type material was designated for these two species by their authors and indeed for *L. birchii* and *L. brunneus* no type specimens of any designation exist (Timms, 2006). For *L. tatei* it is only now that a neotype has been chosen (see earlier). The misspelling of just about every name used, the erection of invalid holotypes and the omission of the other known species of *Limnadopsis*, is enough to cast doubt on this work.

Novojilov (1958) claimed *Limnadiopsium* to be distinct from *Limnadopsis* by reason of the smaller number of appendages, presumably meaning 26 as against 32 in *L. birchii*; spines on the telson being of various dimensions compared with uniform spines in *L. birchii*; the straight dorsal edge of the carapace in *Limnadiopsium*, presumably in contrast to the convex edge in *Limnadopsis*, and the "spines" (= carinae) on the dorsal edge of the carapace being present in all stages of development in *Limnadiopsium* but only in the last stages in *L. birchii*. Detailed studies show that all these claims are spurious. The extent of development of the carinae varies between populations, so that on this character alone, some *L. tatei* and *L. birchii* populations would be excluded from both *Limnadopsis* and *Limnadiopsium* because of not having carinae even as adults. Also, some populations of *L. tatei* do not have a straight dorsal edge to the carapace, so would be excluded, and no female *L. tatei* has a carapace with a straight dorsal edge. As for the telsonic spines, while there is a contrast between *L. tatei* and *L. birchii*, other species show intermediate conditions. Finally, five other species of *Limnadopsis* have 26 trunk segments (25 in some specimens), and *L. minuta* has 24, so that on this character they should be aligned with *L. tatei*, not *L. birchii*. As shown above they are all otherwise distinct from *L. tatei*. In summary, *L. tatei* is not distinctive enough to warrant removal into its own genus *Limnadiopsium*, so Novojilov's (1958) work is rejected.

Biogeography. Two species of *Limnadopsis* (*L. birchii* and *L. tatei*) are widespread in the drier parts of Australia, showing no consistent differences across this broad range. Eastern Australia is populated by just one local species, *L. parvispinus* but in the west and northwest there are five localized species with somewhat different latitudinal distributions (cf. anostracans in Western Australia: Timms, 2002, 2008). Southern Western Australia has *L. paradoxa*, the mid north and northwest has *L. occidentalis*, the northwest has *L. pilbarensis*, and the far north has *L. minuta* and *L. multilineata*. The inland of Western Australia has *L. birchii* and *L. tatei*. Clouding this picture is the presence of isolated populations of the southern Western Australian species *L. paradoxa* in central South Australia and in western New South Wales; perhaps it is spreading to the east from its base in southern Western Australia. The higher diversity of *Limnadopsis* in the west is typical of many organisms of inland waters in Western Australia (e.g., charophytes, A. Garcia, pers. comm.; anostracans, Timms, 2002, 2004, 2008; mytilicyprinid ostracods, Halse and McRae, 2004; many cladocerans, Hebert & Wilson 2000, R. Shiel, pers. comm.). Despite this diversity in Western Australia, no congeneric occurrences have been noted, unlike in the Paroo of the eastern inland, where *L. birchii* and *L. parvispinus* often co-occur (Timms & Richter, 2002).

Key to species

In using this key, it is necessary to be aware of the variability between individuals and populations of the same species. Comparative features in the couplets are arranged so the most reliable are given first, and the least reliable last. While almost all specimens will fit all key features of a given species, occasionally individuals or populations will be aberrant and disagree with one feature, usually the last. In such cases identification should be confirmed using the additional characters given for each species in square brackets.

1 Telson with c. 50 dorsal spines in each row; 32 body segments; most antennal segments with >12 spines ..... *L. birchii* Spencer & Hall

[Also: mature specimens large, generally >18 mm long and up to 30 mm; L:D ratio c. 1.5; 14–16 growth lines; dorsal carinae of growth lines reach forward to proceding growth zone; dorsal surface of telson double-curved in a sinewave; caudal claws evenly curved and with >10 dorsal spines at midlength; carapace with dorsoposterior corner sharp, composed of a protruding growth line carina; eggs round with parallel grooves; carapace usually translucent yellow-brown.]

—— Telson with < 25 dorsal spines in each row; 24–26 body segments; most antennal segments with <10 spines 2

2 Dorsal margin of carapace with irregular, asymmetrical growth line carinae; carapace with robust growth lines; caudal claws with <3 dorsal spines at midlength 3

—— Dorsal margin smooth, or almost so with only very minor steps at each growth line-dorsal margin junction; carapace usually, but not always, with indistinct growth lines; caudal claws with usually >4 dorsal spines at midlength 5

3 Posterior edge of carapace not, or just barely expanded beyond dorsoposterior corner, latter usually bearing a prominent spine; anteriormost dorsal telsonic spine 1.5–2 times size of next few spines; carapace hinge line of male straight or almost so ..... *L. tatei* Spencer & Hall

[Also: mature specimens small, usually <10 mm; L:D ratio c. 1.6; 7–11 (usually <9) growth lines; growth line carinae barely extending into preceding growth zone; these carinae variously developed, sometimes hardly developed at all; 5–7 spines on middle second antennal flagellomeres, all arranged linearly; dorsal surface of telson straight or evenly and slightly concavely curved and bearing two rows of 9–13 (usually c. 12) spines, these sometimes unevenly sized and spaced; caudal claws with straight basal section bearing >12 (rarely as few as 8) proximal setae and <3 dorsal spines at midlength; eggs round with grooves parallel only for short distances; carapace usually translucent yellow-brown.]

—— Posterior edge of carapace expanded into wide curve protruding beyond the dorsoposterior corner, latter bearing a weak spine, if any at all; anteriormost dorsal telsonic spine <1.5 times as large as the next few spines; carapace hinge line markedly curved, even in males 4

4 Dorsal hinge line of carapace in umbo area convexly curved; telson with 12–14 spines evenly spaced; anteriormost telsonic spine c. 1.5 times as large as next few spines ..... *L. pilbarensis* n.sp.

[Also: mature specimens c. 10 mm long with 9–11 growth lines; L:D ratio c. 1.5; dorsal margin of carapace stepped, and with hardly any carinal outgrowths; up to 9 spines on middle flagellomeres of second antenna, all arranged linearly; caudal claw with straight basal section bearing c. 10 proximal setae and <3 (rarely more) dorsal spines at midlength; dorsoposterior corner of carapace blunt with projection at the end of the growth line; eggs round with many (>12) narrow, sharp spikes, pitted between these spikes; carapace yellow with very distinct dark growth lines.]

—— Dorsal hinge line of carapace in umbo area concavely curved, i.e. depressed; telson with 14–18 spines unevenly spaced; anteriormost telsonic spine slightly bigger than next few spines ..... *L. paradoxa* n.sp.

[Also: mature specimens c. 13–15 mm long with 12–13 growth lines; L:D ratio c. 1.5; dorsal margin of carapace markedly stepped or with small carinae at each growth line-dorsal hinge line junction; middle flagellomeres of each second antenna with 6–7 spines on anterior margin, all arranged linearly; caudal claws evenly curved with c. 18 proximal setae and usually just one spine at midlength; dorsoposterior corner of carapace sharp due to a spine-like outgrowth of growth line there; eggs top-shaped (a prominence dorsally and ventrally, and 4–5 equatorially); carapace coloured dark humic brown.]

5 Growth lines in mature specimens >20, often up to c. 30; carapace with a distinct but blunt dorsoposterior corner and with a much expanded posterior/ventroposterior edge; dorsal margin of male carapace almost straight ..... *L. multilineata* n.sp.

[Also: umbo expressed and pointed; L:D ratio c. 1.6; growth lines usually crowded at margin, though this could be due to ecological conditions; height of eye generally less than that of pyriform organ; first antennal lobes c. 6–7; about 18–20 flagellomeres on second antenna, middle ones with 3–5 spines arranged linearly; dorsal telsonic spines 13–18, first spine a little (<1.5) bigger than remainder; caudal claws with c. 15 setae, last few intermixed with c. 5–6 caudal claw spines; eggs bell-shaped; carapace coloured lustrous dark brown.]

—— Growth lines <19; carapace without protruding dorsoposterior corner and posterior edge may be widened but not in ventroposterior area; dorsal margin of male carapace convexly curved 6

6 24 trunk segments; telson with spiniform process on ventroposterior corner below cercopod; 18 growth lines ..... *L. minuta* n.sp.

[Also: carapace <10 mm long; no sexual dimorphism in carapace shape; L:D ratio c. 1.9; lobes on first antenna c. 8 in males and c. 6 in females; flagellomeres of second antenna numbering about 18–20 and middle flagellomeres with c. 4 spines each with 2–3 of these crowded apically, leaving basal anterior surface of segment bare; c. 17 telsonic spines in each row; 12–15 caudal setae, 3–5 caudal spines, posteriormost 3 times larger than others; dorsal surface of telson between spine rows with a marked depression immediately posterior to the insertion mound of telsonic setae; eggs polyhedral.]

—— 25–26 trunk segments; telson without spiniform process on ventroposterior corner.; <17 growth lines 7

7 Dorsal telsonic spines 18–24; cercopods with 4–9 spines at midlength; dorsal telsonic spines evenly sized and spaced ..... *L. parvispinus* Henry

[Also: carapace up to 16 mm in length, L:D ratio c. 1.7; first telsonic spine usually about 1.5 times the next few; middle antennal segments with 4–7 spines each, with perhaps not all linearly arranged; c. 15 setae on caudal claws; 25–26 body segments; dorsal hinge of carapace not depressed at or near umbo; eggs subconical cylinders; carapace of various colours, often variegated brown.]

—— Dorsal telsonic spines c. 13–16; cercopods with 3–5 spines midlength; telsonic spines variable in size and spaci ..... *L. occidentalis* n.sp.

[Also: carapace up to about 12mm in length, L:D ratio c. 1.6; the first telsonic spine variable in size with respect to the others; middle flagellomeres of second antenna with 5–7 spines each, not all arranged linearly; 12–15 setae on caudal claws; 25 body segments; dorsal margin of carapace often depressed at umbo and anterior to it; eggs round with short randomly orientated grooves; carapace various colours often yellowish.]

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